# Duncan Dam Project Water Use Plan

## 2017 Lower Duncan River Kokanee Spawning Monitoring

**Implementation Year 10**
**Data Report and Conclusions 2008-2017**

**Reference: DDMMON-4**

**Study Period: September – October 2017**

**Elmar Plate, PhD 3**
**Joe Thorley, PhD 2**
**Michael Zimmer, MSc 1**

**1 Okanagan Nation Alliance**
**# 101, 3535 Old Okanagan Highway, Westbank, BC, V4T 3J6**
**2 Poisson Consulting Limited**
**4216 Shasheen Road, Nelson, BC, V1L 6X1**
**3 LGL Limited**
**9768 Second Street, Sidney, BC, V8L 3Y8**

**May 2018**

## EXECUTIVE SUMMARY

The Duncan Dam (DDM) Water Use Planning (WUP) process was initiated to address flow management related to local resources such as Lower Duncan River (LDR) Kokanee populations. Monitoring of the abundance of Kokanee spawning in this area was initiated by BC Hydro in 2008 as part of its Water License Requirements (WLR) DDMMON-4 program. Year 2017 represented the tenth and last year of this monitoring program. As in the previous nine years, Kokanee aerial spawner counts were carried out from a helicopter and ground counts were used to verify features of preferred spawning habitats and observer efficiency. Year 10 represents the continuation of the work carried out by ONA and LGL from 2013 to 2016 (Zimmer et al. 2015, Zimmer et al. 2016, Plate et al. 2016, Zimmer et al. 2017) and previously by AMEC from 2008–2012 (AMEC 2009, AMEC 2010, AMEC 2011, AMEC 2012, AMEC 2013). Field methods have been standardized for the duration of this monitoring program to ensure comparability between years. In 2016, the Area Under the Curve (AUC) model was modified so that the uncertainty varied with the annual spawner abundance (Zimmer et al. 2017). The refinement reduced the uncertainty around the abundance estimates for years with lower counts as experienced in 2015, 2016 and 2017.

Based on an Area Under the Curve (AUC) calculation, the 2017 Kokanee spawning population in the Lower Duncan River was estimated to be 1,349 fish, with a lower 95% Confidence Interval (CI) of 244 fish and an upper 95% CI of 3,764 fish. In comparison to previous years, the 2017 estimate is the lowest on record, about 66% of the previous lowest estimate of 2,104 Kokanee in 2015 (Lower CI = 725; Upper CI = 4,488) and about 4% of the highest estimate of 32,182 in 2011 (Lower CI = 16,057; Upper CI = 65,504). Similar to the results of previous years, both Meadow Creek (4,346 fish) and the Lardeau (6,281 fish) system had a higher estimated number of spawners than the LDR in 2017, but both systems also experienced by far the lowest Kokanee escapement over the last ten years.

Similar to 2013 and 2016, BC Hydro proposed and implemented elevated minimum flows of 90 - 100 $m^3/s$ discharge in LDR (as measured at WSC Station 08NH118) during the spawning period. In support of previous years' recommendations, these minimum flows were initiated early on September 25, 2017 to protect redds from dewatering during peak spawning.

Specific management questions defined in the DDMMON#4 Terms of Reference (TOR) and the progress made in addressing them in 2017 is summarized in Table 1.

Table 1: Management questions and the status of the answers to them based on field work and data analysis carried out as part of the BC Hydro project DDMMON-4 from 2008-2017.

| Management Question | Status |
|---|---|
| What is the spawn run timing, fry emergence timing, and relative intensity of Kokanee spawning in the Lower Duncan River?<br><br>What potential operational/environmental cues affect this variable? | <u>Spawn Run Timing:</u> Based on the results of the current study Kokanee can spawn in the LDR from early September to late October with peak spawning occurring from September 24 to October 10. In 2017, the peak of Kokanee spawning activity was estimated for October 3.<br><br>In the ten years of study, changes in LDR flow and a decreasing seasonal trend in water temperature have not been shown to trigger changes in spawning migration or the distribution pattern of Kokanee spawners in the LDR. |

| | |
|---|---|
| | <u>Fry Emergence Timing:</u> In general, fry emergence timing is dependent on the Accumulated Thermal Units or ATUs of fish eggs during incubation and early development. Kokanee typically accumulate 900–950 thermal units from spawning to emergence from the gravel (Quinn 2005). Based on the water temperature WSC station 08NH118 it is estimated that depending on the year, emergence can start as early as December 20 and end May 5. Peak emergence is estimated to occur from February 7 to April 10.<br><br>Based on observations in AMEC (2013) and ONA and LGL (Zimmer et al. 2015; Zimmer et al. 2016, Plate et al. 2016, Zimmer et al. 2017), the DDM low level outlets (LLOs) discharge water may be warmer than surface waters in the winter, resulting in emergence timing that is earlier for LDR Kokanee than seen in adjacent systems such as Meadow Creek and Lardeau River. In general, higher winter DDM discharges reservoir elevations result in higher temperatures over incubation.<br><br><u>Relative Intensity of Spawning in the LDR in Comparison to Lardeau River and Meadow Creek:</u> In 2017, the highest number of spawning Kokanee was observed in the Lardeau system, representing 53% of the total count for the three systems. Meadow Creek represented 36% of the count, and the Lower Duncan River represented 11% of the total count. In all other years than 2015 and 2016, Kokanee escapement to Meadow Creek and Lardeau River always represented either 94% as in 2014 or typically >97% (2008-2013) of the total Duncan system Kokanee run. |
| What are the timing/cues of Kokanee spawners in Meadow Creek and Lardeau River systems? | <u>Spawn Timing Cues:</u> Kokanee spawning in Meadow Creek occurs from mid-August to late October with peak spawning observed most commonly in the last week of September as in 2015 and in 2011 or the first week of October as in the other six years of the study (AMEC 2013; Zimmer et al. 2015; Zimmer et al. 2016, Plate et al. 2016, Zimmer et al. 2017). However, peak spawning occurred in the first week of September at Meadow Creek in 2016 (Zimmer et al. 2017) and 2017. In this context, water temperature does not appear to influence neither the arrival of Kokanee in the LDR nor their spawn timing. In 2017, water release through DDM was kept constant throughout the spawning period (September 25 - October 23) and therefore neither water temperature nor discharge fluctuated enough to act as a possible cue for spawn timing or river entry.<br><br>It is known that Kokanee spawn in the Lardeau River from early September to mid-October but it is unknown which environmental cues trigger river entry or spawning in the Lardeau River (AMEC 2013). |
| What are the relative distribution of Kokanee spawners in the Lower Duncan River, Meadow Creek and Lardeau River? What potential operation/ environmental/ physical | <u>Kokanee Spawner Distribution in the LDR:</u> As in previous years, Kokanee were observed to spawn between Kilometers 1.4 and 9.5 (See Appendix A). No redds were observed upstream of Kilometer 1.4 from Duncan Dam which is the upstream end of the study reach, or from Kootenay Lake (downstream end of the study reach) to River km (Rkm) 9.5. Most notable concentrations of spawning Kokanee in 2017 were found between Rkm 1.5-3.1 where 70% of the spawning Kokanee within the study reach were |

| | |
|---|---|
| cues (e.g., temperature, velocity, depth, cover, substrate) affect this variable? | observed. These river stretches have been consistently used for spawning for the last five years, but it was not the mandate of DDMMON-4 to accurately characterize them. Based on visual observations made during aerial surveys, the preferred spawning reaches can be described as characterized by medium current velocity (0.3-1 m/s), depths ranging from 0.5-1.5 m, substrate composed mainly of gravel (4-80 mm diameter) with intermittent shading but little direct tree cover.<br><br>Side channel (SC) use for spawning in 2017 was observed pre-flow reduction on September 22 in SC 1.1R (68 fish) and in SC 4.1R and SC 4.4R post-flow reduction on September 29 (42 fish) (See Appendix A).<br><br><u>Kokanee Spawner Distribution Meadow Creek:</u> As specified in the study terms of reference, no additional work with regards to Kokanee spawner distribution in Meadow Creek was carried out past Year 4 of the monitoring program. Based on previous studies (AMEC 2013), the majority of spawning occurs in the 3 km of Meadow Creek Spawning Channel (located approximately 4 km upstream of the confluence with the Lower Duncan River) with idealized conditions for Kokanee egg incubation. Areas outside of the spawning channel are mainly used when the spawning channel itself is filled to capacity with Kokanee spawners (AMEC 2013). The substrate of the lower section of Meadow Creek has a high percentage of silt and fewer spawning gravels and is therefore limited in suitability for Kokanee spawning (Quamme 2008).<br><br><u>Kokanee Spawner Distribution Lardeau River:</u> As specified in the study terms of reference, no additional work with regards to Kokanee spawner distribution in Lardeau River was carried out past Year 4 of the monitoring program. Based on previous studies (AMEC 2013), Kokanee spawning in the Lardeau River has been observed along its whole length with the highest densities found in the upriver side channels. Based on its natural hydrograph, the Lardeau River experiences typical spring flush flows that aid in removing fines (AMEC 2013).<br><br>As a general comment, genetic analysis of Kokanee spawning in the LDR, Lardeau River and Meadow Creek revealed that Kokanee spawners from the three locations are not genetically different. They are therefore considered to belong to the same Kokanee stock (AMEC 2012; Lemay and Russello 2012). |
| What physical works or operational constraints could be implemented to minimize operational conflicts associated with recommended Kokanee spawning operations? | A primary goal of this study is to evaluate the effectiveness and impacts of the Water Use Plan's Kokanee protection flow regime. Several factors are limiting the ability to manipulate flows during the late September – early October period, including operations agreements (Columbia River Treaty and International Joint Commission). In addition, very limited feasibility of physical works to prevent Kokanee from accessing side channels affected by the spawning flows (AMEC 2012) has been determined. It is recommended that the DDM Works 4 program *("Action Plan to Minimize Risk of Stranding Spawning Kokanee")* utilize the information gathered in |

| | |
|---|---|
| | this monitoring program to evaluate alternatives that minimize impacts to the early Kokanee spawning run, in consideration of operating agreements (Columbia River Treaty, International Joint Commission) and other Water Use Plan objectives (flood control and recreation). The outcome of this analysis would be used to inform future Water Use Plan review processes on opportunities that minimize stranding while accommodating other important water use objectives. Notwithstanding the continued low escapement to the LDR, Meadow Creek and Lardeau River, DDM operations should continue to be sensitive to the known Kokanee spawning period in the LDR. |

## ACKNOWLEDGEMENTS

The authors would like to acknowledge the following people for their contribution to this project:

**BC Hydro**

We gratefully acknowledge the input and guidance provided by Darin Nishi, Philip Bradshaw, Katy Jay, Jason Watson, Trish Joyce and Alf Leake of BC Hydro.

**Ministry of Environment**

Special thanks go to Matt Neufeld and Murray Pearson of the Ministry of Forests, Lands and Natural Resource Operations for input to field preparation and providing Meadow Creek and Lardeau River Kokanee spawner counts.

**Okanagan Nation Alliance**

We gratefully acknowledge the contributions of Gerry Nellestijn as the initial (September 22 and 29) and from then on primary counter with Dixon Terbasket (ONA) in the helicopter and ONA Technician Autumn Solomon for counting during the ground surveys.

**LGL Limited**

Thanks to Lucia Ferreira of LGL Limited who prepared all maps for this study and estimated wetted widths and areas based on mapping data.

## TABLE OF CONTENTS

## LIST OF TABLES



## LIST OF FIGURES

## APPENDICES

## IMPORTANT NOTICE

This report was prepared exclusively for BC Hydro by the Okanagan Nation Alliance (ONA) in collaboration with LGL Limited and Poisson Consulting Limited. The quality of information, conclusions and estimates contained herein is consistent with the level of effort involved in ONA, LGL and Poisson services and based on: i) information available at the time of preparation, ii) data supplied by outside sources, and iii) the assumptions, conditions and qualifications set forth in this report. This report is intended to be used by BC Hydro only, subject to the terms and conditions of its contract with the ONA, LGL and Poisson. Any other use of, or reliance on, this report by any third party is at that party's sole risk.

# 1.0 INTRODUCTION

The Duncan Dam (DDM) was constructed from 1965 to 1967 for water storage under the Columbia River Treaty (CRT). Since 1967, the Lower Duncan River has been managed as a regulated river and is operated by BC Hydro for flood control. The dam, situated 12.4 kilometers upstream of the north end of Kootenay Lake, regulates water levels in the Lower Duncan River (LDR) through daily, seasonal and annual operations (Figure 1) (AMEC 2013). The complexity of up and downstream ecological function, and social and economic interests of the many users of the LDR and Kootenay Lake poses many challenges for the operation of DDM. Therefore, a Water Use Planning (WUP) consultation process was initiated in 2001 to address flow management issues with respect to impacts on competing resources (BC Hydro 2004, AMEC 2013). The DDM WUP Consultative Committee (CC) identified Kokanee (*Oncorhynchus nerka*) spawning success in the LDR as a valuable ecosystem component that could be impacted by DDM operations (BC Hydro 2007).

As a result of the CC's recommendations, Kokanee escapement in the LDR has been monitored under BC Hydro's DDMMON-4 since 2008. During the initial 5 years of the project (2008-2012), Kokanee escapement was assessed by AMEC (AMEC 2009-2013) and in 2013, ONA partnered with LGL to continue monitoring (Zimmer et al. 2015; Zimmer et al. 2016, Plate et al. 2016, Zimmer et al. 2017).

## 1.1 Objectives

DDMMON-4 is a 10-year project with the following specific objectives. Bolded objectives were addressed in Year 10 (2017) of this study and remaining objectives were addressed from 2008–2016 (AMEC 2009-2013; Zimmer et al. 2015; Zimmer et al. 2016, Plate et al. 2016, Zimmer et al. 2016):

1. **Document the annual Kokanee escapement to the Lower Duncan River**, Lardeau River, Meadow Creek, and Meadow Creek Spawning Channel;
2. **Document Kokanee spawning in the Lower Duncan River within and outside of operational constraints**; and;
3. Define Kokanee spawning habitat preferences, timing and Kokanee morphology between spawning runs in the Lower Duncan River, Lardeau River and Meadow Creek for consideration of future decisions.

DDMMON-4 is structured around the following Management Questions based on the associated Terms of Reference (BC Hydro 2008) and Scope of Services. Bolded Management Questions were addressed in Year 10 (2017) and remaining management questions were addressed from 2008–2016 (AMEC 2009-2013; Zimmer et al. 2015; Zimmer et al. 2016, Plate et al. 2016, Zimmer et al. 2017):

1. **What is the spawn run timing, fry emergence timing, and relative intensity of Kokanee spawning in the Lower Duncan River**? **What potential operational/environmental cues affect this variable**?
2. **What are the timing/cues of Kokanee spawners in Meadow Creek and Lardeau River systems**?
3. **What are the relative distribution of Kokanee spawners in the Lower Duncan River, Meadow Creek and Lardeau River**? **What potential operation/environmental/physical cues (e.g., temperature, velocity, depth, cover, substrate) affect this variable**?; and

4. What physical works or operational constraints could be implemented to minimize operational conflicts associated with recommended Kokanee spawning operations?

## 1.2 Purpose

The purpose of this monitoring program is to evaluate the effectiveness and impacts of operational constraints defined in the DDM WUP. 2017 marked the tenth year of the 10-year monitoring program for DDMMON-4. This report fulfills the ONA and LGL commitment to provide BC Hydro with a data report for the 2017 (Year 10) monitoring of Kokanee spawning in the LDR.

Similar to 2013 and 2016, for 2017 BC Hydro proposed and implemented elevated minimum flows during the spawning period of around 90-100 $m^3/s$ discharge in LDR (as measured at WSC Station 08NH118) and with an earlier initiation date (September 25), in support of previous years' recommendations to protect redds from dewatering during peak spawning. As part of DDMWORKS#4, this earlier (typically Sept 27) reduction to minimum flows, was proposed to test effects on reducing redd stranding and subsequent predicted egg desiccation and mortality.

# 2.0 METHODS

## 2.1 Study Area

The LDR is fed by DDM and the Lardeau River at its upstream end and flows over a distance of approximately 12.4 km into the north end of Kootenay Lake, which is located north of Nelson in southeastern British Columbia. The Duncan River watershed above DDM is fed by numerous tributaries flowing from the Selkirk and Purcell mountain ranges. The 2017 monitoring study covered the entire 12.4 km of LDR from DDM (River Rkm 0.0) to Kootenay Lake (Rkm 12.4) inclusive of side channels (Figure 1).

## 2.2 Environmental Parameters

Influence of hourly discharge through DDM and related water temperature records for the LDR (below the Lardeau River confluence) were obtained from the Water Survey of Canada (WSC) gauge 08NH118 (Water Survey of Canada 2017). These parameters were used to investigate relationships to Kokanee spawning onset, spawner abundance and distribution and potential desiccation of eggs.

## 2.3 Sample Timing

A summary of Kokanee spawning monitoring dates and methods for 2017 is summarized in Table 2. Sampling methods included four visual Kokanee counts from a helicopter and simultaneous aerial redd mapping. Initially, five flights were planned, however chronic turbid conditions postponed the initial flight by seven days. During two aerial flights, one pre flow reduction (September 22) and one two weeks post flow reduction (October 11), stream walks were carried out on selected side-channels to assess observer efficiency for the helicopter counts. The selected side-channels were standardized locations from previous years. They typically had clear water and were un-shaded and thus offered optimum fish viewing conditions from the ground and air. As in 2016, an additional 700 m site along the main stem of Meadow Creek upstream of Highway 31 was included as a contingency if low or zero counts were documented in the LDR ground-count side channels. Meadow Creek, in the calibration reach is not influenced by DDM operations. During the stream walks, ground counters verified their counts with one another through independent surveys of each section. The combined ground stream counts were used to determine helicopter observer efficiency.


Figure 1: Lower Duncan River (LDR) study area for DDMMON 4 Kokanee enumeration and redd surveys (adapted from AMEC 2013).

Table 2: Sample timing, survey conditions and survey type for DDMMON-4 Lower Duncan River Kokanee spawner monitoring.

| Survey Date | Survey Conditions | Water Clarity | Survey Type | Helicopter Type |
|---|---|---|---|---|
| September 22 | Sunny-cloudy | Medium (< 1 m) | Aerial and Ground Count (pre-flow reduction to 100 $m^3/s$) | Twin Engine, BO105LS |
| September 29 | Sunny-clear | High (> 1 m) | Aerial | Twin Engine, BO105LS |
| October 11 | Sunny-cloudy | High (> 1 m) | Aerial and Ground Count (post-flow reduction to 100 $m^3/s$) | Twin Engine, BO105LS |
| October 23 | Sunny-cloudy | High (> 1 m) | Aerial | Twin Engine, BO105LS |

## 2.4 Helicopter Enumeration Surveys

All helicopter aerial surveys covered the entire length of the LDR from the delta in Kootenay Lake flying upstream to approximately 200 m below DDM. Aerial surveys also covered all LDR side channels following the protocol used from 2008–2016 (AMEC 2009-2013; Zimmer et al. 2015; Zimmer et al. 2016, Plate et al. 2016, Zimmer et al. 2017). In 2017, all surveys were carried out using a BO105LS twin engine helicopter operated by Dam Helicopters (Castlegar, BC) and piloted by Duncan Wassick, who had operated the helicopter in previous surveys for DDMMON-4.

During the surveys, fish were counted visually and numbers recorded with tally counters by the lead fish counter in the front of the helicopter. To ensure the lead counter had an approximately 180$^o$ view of the river, the pilot flew upstream at a 45$^o$ angle to the direction of the current. The behaviour (holding, migrating, spawning or dead), number of spawners and the extent of the area that Kokanee were using was then manually drawn on a detailed 1:2,000 orthophoto and later geo-referenced digitally as a polygon layer. The crew member in the back seat of the helicopter also tallied Kokanee observed using the same visual methods and recording materials. On the orthophotos of the main stem and the side-channels, 100 m orientation markings helped to pinpoint the exact location of Kokanee over each of the four surveys. Each side channel and main stem reach was named and the naming conventions conformed to the conventions established in the 2008-2016 studies (AMEC 2009–2013, Zimmer et al. 2015, Zimmer et al. 2016, Plate et al. 2016, Zimmer et al. 2017). The lead counter categorized Kokanee behaviour as follows:

- **Holding** – Kokanee observed in a school that were holding stationary often in calmer eddies and did not appear to be spawning;
- **Migrating** – Kokanee observed in a school that were moving in a line in an upstream direction and did not appear to be spawning;
- **Spawning** – Kokanee observed stationary, paired up and distributed evenly throughout an area (sometimes redd digging was observed); and
- **Dead** – Kokanee observed drifting at the surface belly up without any volitional movement.

All flights were conducted at approximately 20–40 m above the ground at a speed of 10–18 km/hr upstream and conformed to BC Hydro's flight plan requirements. Depending on the terrain, safety hazards, and weather conditions, the helicopter had to increase elevation or speed at times. During each survey, the main stem of the LDR was surveyed first followed by individual side channels to ensure the surveys could be carried out in a systematic and consistent manner (AMEC 2013; Zimmer et al. 2015; Zimmer et al. 2016, Plate etal. 2016, Zimmer et al. 2017). For the first two flights in 2017, Elmar Plate was the lead enumerator and Gerry Nellestijn the secondary. For the last two flights, Gerry Nellestijn was the lead enumerator and Dixon Terbasket (ONA) was the secondary enumerator. Elmar Plate and Gerry Nellestjin, have conducted surveys for this project in previous years and therefore replicated methods used previously. Dixon Terbasket was introduced to the same fish enumeration methods and had considerable experience in aerial and helicopter based wildlife assessments.

## 2.5 Data Analyses

### 2.5.1 Data Preparation

The 2017 survey data were provided by LGL Limited in the form of Excel tables. They were imported into the existing SQLite database. The data were clean and tidied (Wickham 2014) using R version 3.4.3 (R Core Team 2016).

The mean daily discharge and water temperature values at Duncan River below Lardeau (DRL) were extracted from BC Hydro's environmental database for the Kootenays, which is maintained by Poisson Consulting. The annual abundances of Kokanee spawning in Meadow Creek and the Lardeau River were provided by the Ministry of Forests, Lands and Natural Resource Operations (M. Neufeld, unpublished data 2017).

### 2.5.2 Statistical Methods

The Area Under the Curve or AUC estimates were produced using JAGS (Plummer 2015). For additional information on Bayesian estimation the reader is referred to McElreath (2016). Unless indicated otherwise, the Bayesian analyses used uninformative normal prior distributions (Kery and Schaub 2011, 36). The posterior distributions were estimated from 1500 Markov Chain Monte Carlo (MCMC) samples thinned from the second halves of 3 chains (Kery and Schaub 2011, 38–40). Model convergence was confirmed by ensuring that $\widehat{R} \leq 1.1$ (Kery and Schaub 2011, 40) and $\mathrm{ESS} \geq 150$ for each of the monitored parameters (Kery and Schaub 2011, 61). Where $\widehat{R}$ is the potential scale reduction factor and $\mathrm{ESS}$ is the effective sample size.

The parameters are summarised in terms of the point *estimate*, standard deviation (*sd*), the *z-score*, *lower* and *upper* 95% confidence/credible limits (CLs) and the *p-value* (Kery and Schaub 2011, 37, 42). The estimate is the median (50th percentile) of the MCMC samples, the z-score is $\mathrm{sd}/\mathrm{mean}$ and the 95% CLs are the 2.5th and 97.5th percentiles. A p-value of 0.05 indicates that the lower or upper 95% CL is 0. Where relevant, model adequacy was confirmed by examination of residual plots for the full model(s).

The results are displayed graphically by plotting the modeled relationships between particular variables and the response(s) with the remaining variables held constant. In general, continuous and discrete fixed variables are held constant at their mean and first level values, respectively, while random variables are held constant at their typical values (expected values of the underlying hyperdistributions) (Kery and Schaub 2011, 77–82). When informative the influence of particular variables is expressed in terms of the *effect size* (i.e., percent change in the response variable) with 95% confidence/credible intervals (CIs, Bradford, Korman, and Higgins 2005).

The analyses were implemented using R version 3.4.3 (R Core Team 2015) and the mbr family of packages.

### 2.5.3 Observer Efficiency

Observer efficiency was based on a comparison of fish counts between ground counters and aerial counters over the exact same sections. In 2017, ground surveys were completed on September 22 and October 10 and 11 at known side channel locations (i.e., SC R3.5, SC R6.9 and SC L8.2) in the LDR and also included a 700 m section of Meadow Creek. The ground surveys were conducted on the same day as the aerial surveys, immediately prior or past the fly-over, coordinated via radio communication. Of note however, mechanical challenges caused the helicopter to abort the flight pre-flight prep on October 10, and once becoming known to the ground crew (via satellite phone), the remaining ground calibrations were postponed to the next day once helicopter repairs were made.

In 2017 as in 2016, all the available data were aggregated into a single database and the aerial and ground counts for all years were recalculated based on the raw data. A consequence of this consolidation was a change in the ground counts, which affected the estimates of observer efficiency. The counts were summed for each visit to each section of river. When there were repeated counts for a channel the higher of the two values was chosen. The aerial observer efficiency was estimated from the ground counts using an overdispersed Poisson regression. Key assumptions of the observer efficiency model include:

- The ground counts are accurate.
- The error in the aerial counts is gamma-Poisson distributed.

Prior to 2016 the model, assumed that both the ground and aerial counts included error.

### 2.5.4 Area Under the Curve (AUC) Abundance Estimates

Repeated spawner counts can be converted into abundance estimates by dividing the area under the spawner curve (AUC) by the observer efficiency and residence time (English et al. 1992) where the residence time is the number of days individual fish typically spend on the spawning grounds. With the inclusion of an arrival time model, the method provides a basis for statistically describing uncertainty (Hilborn et al. 1999) and estimating spawn timing. When data is sparse, hierarchical methods allow “borrowing strength” from years with informative data to improve estimates for years with uninformative data (Su et al. 2001). Here we used hierarchical Bayesian AUC methods with a normal arrival time model and fixed duration to estimate spawn timing and spawner abundance with credible intervals (CIs). In 2016 and 2017, the model was revised to allow the uncertainty in the spawner counts to vary with the annual abundance. The change resulted in a substantial reduction in the uncertainty of estimates particularly for years with lower counts.

Key assumptions of the AUC model include:

- Spawner arrival and departure times are normally distributed (Hilborn et al. 1999).
- Spawner duration is constant across years.
- Spawner abundance varies randomly by year.
- Peak spawn timing varies randomly by year (Su et al. 2001).
- Spawner residence time is between 7 and 14 days (Acara 1970, Morbey and Ydenberg 2003).

- Spawner observer efficiency is drawn from a normal distribution as estimated by the observer efficiency model, with a mean of 1.40, SD of 0.38 and lower and upper limits of 0.89 and 2.39, respectively.
- The standard deviation of the residual variation in the spawner counts varies by the annual abundance.
- The residual variation in the spawner counts is normally distributed.

### 2.5.5 Emergence Timing

The emergence timing was calculated from the daily water temperature at DRL assuming 950 Accumulated Thermal Units (ATUs). The relationship between peak spawn timing and the mean September water temperature at DRL was tested using linear regression. Neither relationship was statistically significant ($p > 0.3$).

### 2.5.7 Potential Egg Deposition and Losses

Potential egg deposition (PED) and loss calculations followed AMEC's previous methods and assumptions on dewatering effects, spawn timing/superposition/predation, multiple-redd construction and sex ratios (AMEC 2012, AMEC 2013). Peak counts were used to estimate female numbers, and egg deposition for LDR Kokanee. To determine average fecundity per female, the average egg retention of 4 eggs was subtracted from the average fecundity of 225 eggs per female (AMEC 2012) for a total of 221 eggs spawned per female. Potential egg deposition was calculated as follows:

Peak count prior to flow reduction x 0.5 = Number of Females ($N_f$)
Potential eggs deposited per female ($PED_f$) = fecundity – egg retention
Potential total eggs deposited ($PED_t$) = $N_f$ x $PED_f$

A second calculation of PED and loss was also included for 2017. Since Kokanee size (length, weight) in 2016 and 2017 had notably increased since 2014 (based on enumerator observations), when fecundity data were collected by AMEC (2011), it was speculated that fecundity had also increased. Based on the Meadow Creek Spawning Channel biological assessment in 2017, it was confirmed that fecundity had more than tripled to an average 724 eggs with an average retention of 4 eggs for an average of 720 eggs spawned per female (M. Neufeld, pers. comm., MFLNRO, unpublished data). For comparison, calculations using historical and current average fecundity were included in this report.

Redd mapping exercises were conducted during all flights and therefore on September 22 (prior to pre-spawning flow reduction) and September 29 (post flow reduction). Potential egg losses (PEL) were calculated separately for side channel and main stem redds that were dewatered throughout the duration of the study period (September 22 to October 23, 2017). The 1:2,000 orthophotos with hand drawn redd locations were geo-referenced using ArcGIS™ software to measure areas of redds. To calculate PED, comparisons of observed redd locations (area in $m^2$) in side channels and main stem before and after flow reductions were made (September 22 and September 29, respectively). Totals egg loss (PEL) from flow reduction was calculated using total eggs deposited, total area of spawning, compared to area of spawning dewatered as a result of DDM flow reduction, using the following equation:

Potential total eggs deposited ($ED_t$) / Pre-flow reduction Spawning Area ($SA_{pre}$) = Eggs/$m^2$
Total potential egg loss ($PEL_t$) = Spawning Area dewatered ($m^2$) x Eggs/$m^2$

Subsequently:

$$\text{Potential egg loss in Side channels } (PEL_{sc}) = \text{Spawning Area dewatered in Side Channels } (m^2) \times \text{Eggs}/m^2$$
$$\text{Potential egg loss in Mainstem } (PEL_{ms}) = \text{Spawning Area dewatered in Mainstem } (m^2) \times \text{Eggs}/m^2$$

Such that:

$$PEL_t = PEL_{sc} + PEL_{ms}$$

## 3.0 RESULTS

### Environmental Parameters

### 3.1 Lower Duncan River Discharge and Temperature

Based on data collected from Lower Duncan River Water Survey Canada (WSC) hydrometric station 08NH118 (

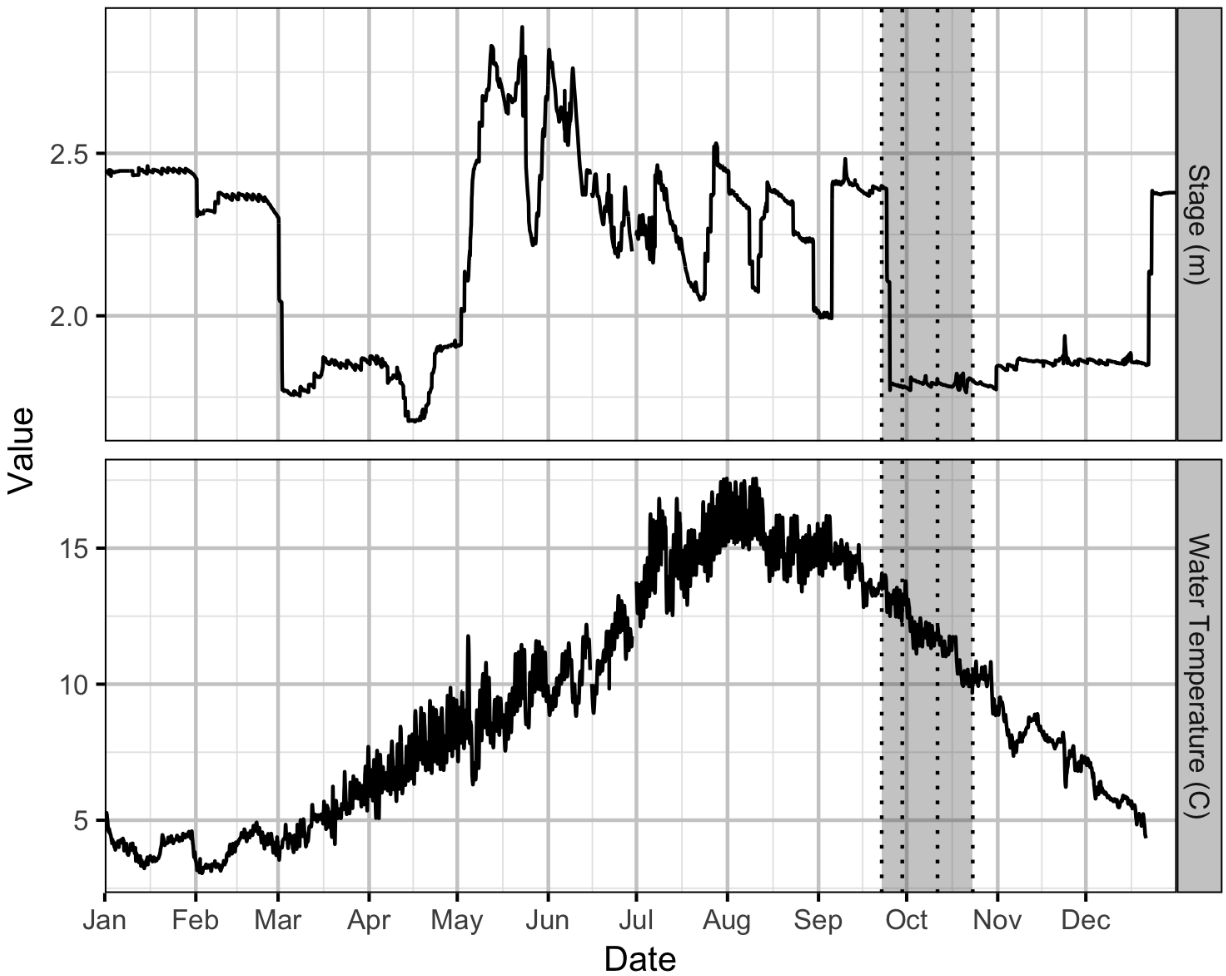


Figure 2, Figure 3), the Kokanee spawning period in September and October 2017 was characterized by a regulated decrease in primary water level and discharge from summer period flows through a step-wise decrease during the spawning period in late September as part of Columbia River Treaty flow release commitments (A. Leake, BC Hydro, pers comm). Summer flows were stepped down from 232 $m^3/s$ on September 23, 2017 in two steps: to 155 $m^3/s$ on September 24; down to 95 $m^3/s$ on September 25; where they stayed until early November (Figure 3).The two flow reductions between September 23 and 25 lowered the primary water level in the LDR from 2.40 m to 1.80 m (Figure 2, Figure 3), which was similar to 2013-2016 and slightly higher than the previous surveys from 2008 to 2012.

Daily average water temperature data was summarized from the WSC station (Figure 3) to determine any correlations to timing of spawning and to predict incubation and emergence timing. Temperatures during spawning and through the duration of the field investigations followed seasonal trends, from 14.2 °C to 11.5 °C (September 15-October 18), decreasing to the lowest temperature of 9.4 °C on October 30.

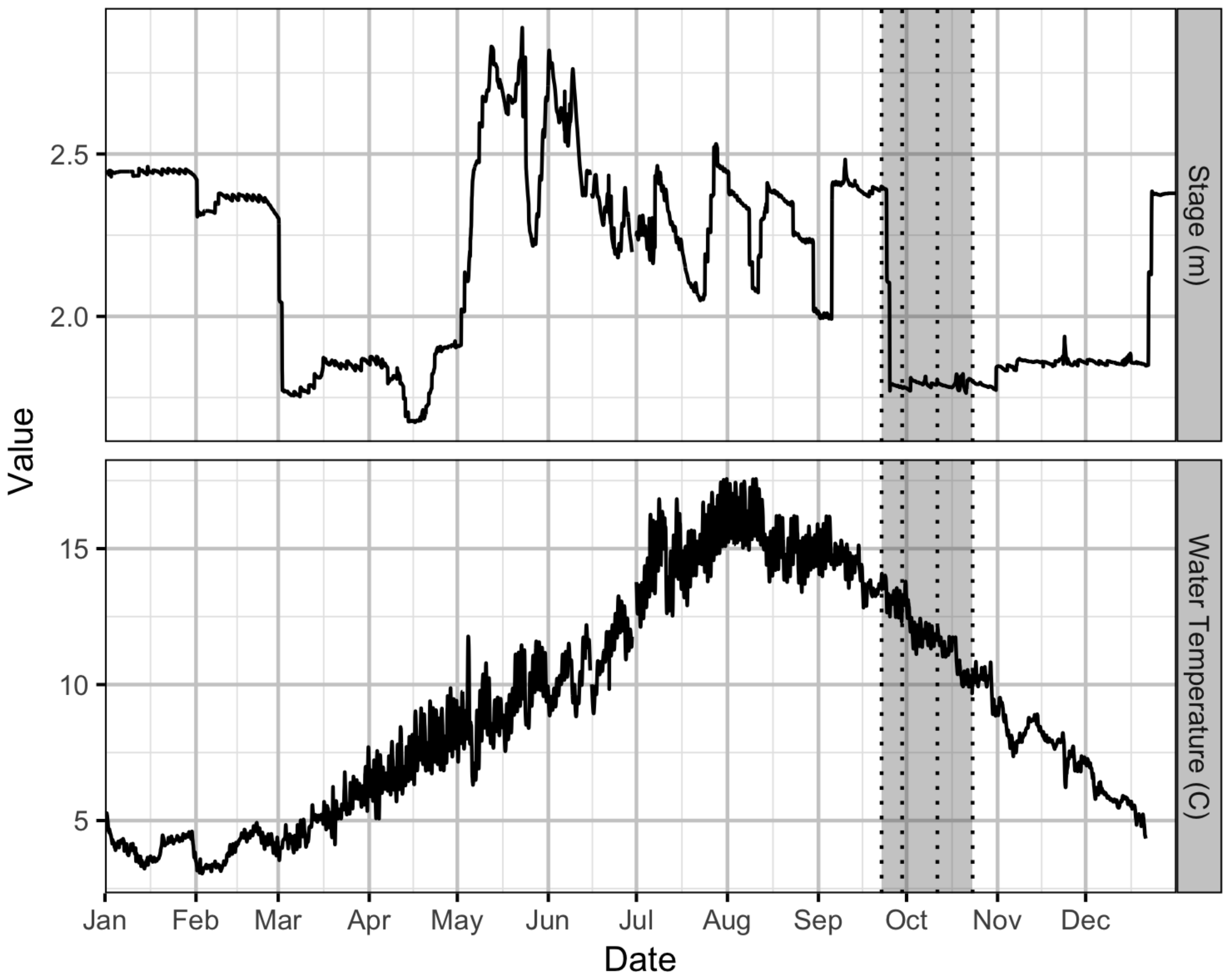


Figure 2: Primary water level (m) and temperature (°C) for Lower Duncan River at Lardeau River confluence for 2017 (Source: Water Survey of Canada Stn. 08NH118). The grey polygon indicates Kokanee enumeration study period for DDMMON 4 2017.

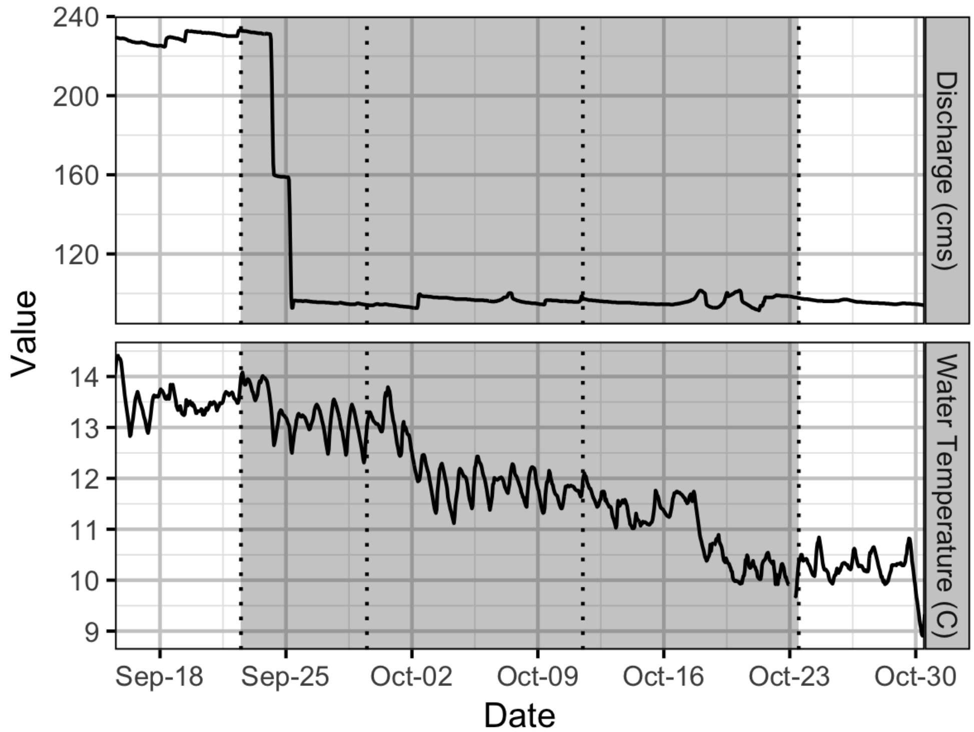


Figure 3: Lower Duncan River (Stn 08NH118) discharge ($m^3/s$) and water temperature (°C) for the survey period (grey area) downstream of the confluence with the Lardeau River, September 15 – November 1, 2017 (Source: Water Survey of Canada). Survey dates are indicated by the dashed lines.

Discharge patterns through DDM for the LDR changed considerably over the last ten years (Figure 4). From 2008 – 2012 and in 2014, September discharges ranging from 210 – 235 $m^3$/s were reduced to 72 – 76 $m^3$/s, before they were increased to 100 – 110 $m^3$/s approximately one month later where they stayed until late December. In 2015, flows were also reduced to 75 $m^3$/s but were increase back to ~240 $m^3$/s at the end of October where they stayed until late December. In 2016 and 2017, flows were reduced in two steps from ~230 $m^3$/s to ~100 $m^3$/s around September 23 and were left at this discharge until late November.

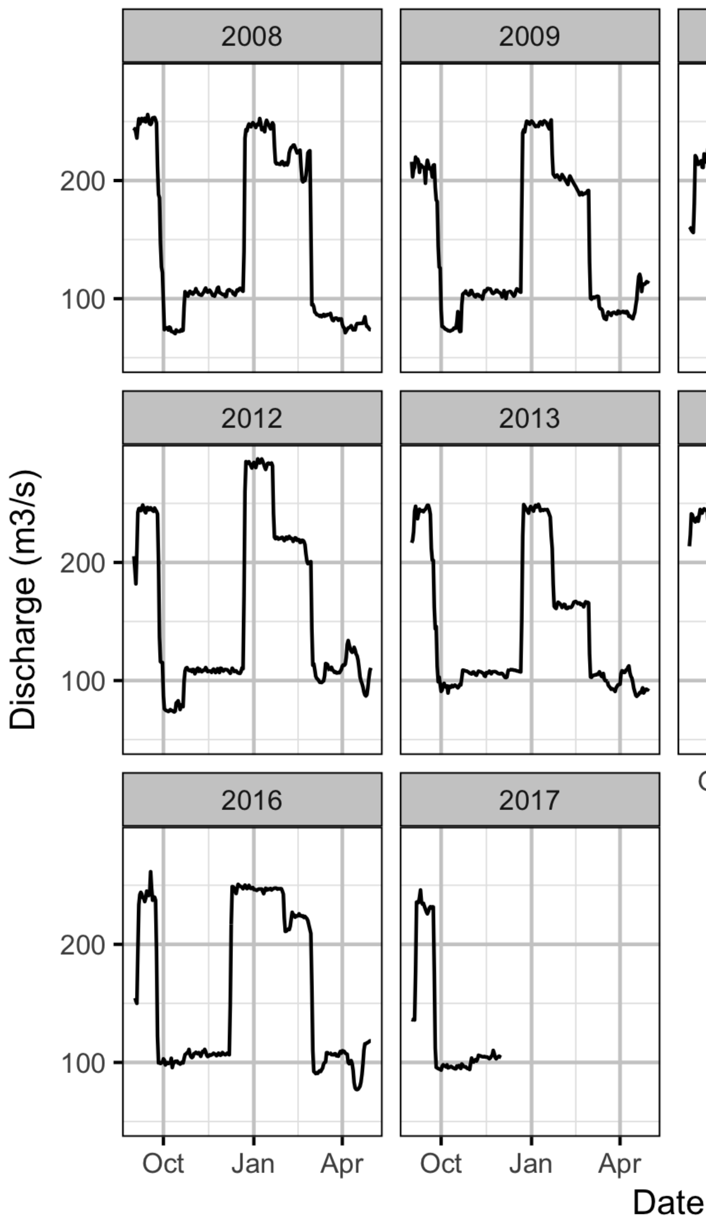


Figure 4 Mean daily discharge at DRL by spawn year.

## 3.2 Calibration of Observer Efficiency

The observer efficiency for 2017 was 50% based on calibration counts of fish holding in Meadow Creek. No fish could be observed in either the aerial or the ground counts in Side Channels 3.5R, 6.9R and 8.2L. Similar to 2016, a contingency of sampling a section of Meadow Creek was invoked in the event that none to very few Kokanee were observed during flights over Side Channels 3.5R, 6.9R, or 8.2L. During calibration ground counts, all (6 of 6) of Kokanee were counted in the contingency section of Meadow Creek.

Table 3 summarizes results of all DMMMON-4 ground calibration counts for the aerial counts from 2008 to 2017. Figure 5 summarize the relationship between aerial versus ground counts and predicts through the linear relationship between the two variables that aerial counts are moderately higher than the ground counts mainly based on initial DDMMON-4 years from 2008-2010. Due to the changes in the ground counts and observer efficiency model, the estimate of the overall observer efficiency increased from 1.06 (95% CI 0.69, 1.50) in 2015 to 1.40 (95% CI 0.89, 2.40) in the current analysis.

Table 3: Aerial and ground Kokanee calibration counts for standardized locations in the LDR from 2008-2017.

| Date | Channel | Aerial Count | Ground Count |
|---|---|---|---|
| 2008-09-24 | 6.9R | 1710 | 1484 |
| 2009-09-22 | 3.5R | 75 | 45 |
| 2009-10-02 | 3.5R | 100 | 101 |
| 2009-09-22 | 8.2L | 172 | 75 |
| 2009-10-02 | 8.2L | 15 | 35 |
| 2009-10-09 | 8.2L | 10 | 299 |
| 2010-10-06 | 3.5R | 822 | 284 |
| 2011-09-29 | 3.5R | 5720 | 2518 |
| 2011-09-29 | 6.9R | 230 | 490 |
| 2014-09-27 | 3.5R | 20 | 7 |
| 2014-09-27 | 8.2L | 294 | 285 |
| 2016-09-23 | 3.5R | 2 | 3 |
| 2016-09-23 | Meadow Creek | 61 | 67 |
| 2016-09-29 | Meadow Creek | 29 | 30 |
| 2017-09-22 | Meadow Creek | 2 | 4 |

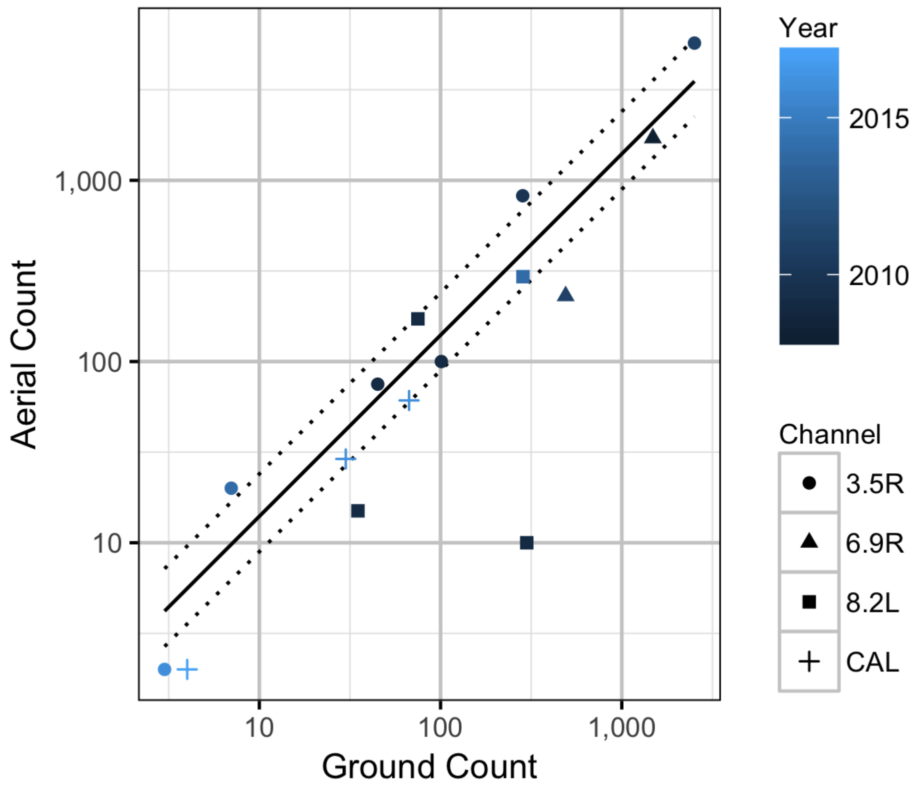


Figure 5: Aerial versus ground Kokanee spawner counts on log scales by year and channel from 2008 to 2017. The solid line is the predicted relationship between the aerial counts and the dotted lines are 95% CIs.

## 3.3 Area Under the Curve Estimates

AUC estimates of daily and total LDR Kokanee spawner abundance for 2017 and all previous sampling years are presented in Figure 6 and Figure 7, respectively. Based on an Area Under the Curve (AUC) calculation, the 2017 Kokanee spawning population in the Lower Duncan River was estimated to be 1,349 fish, with a lower 95% Confidence Interval (CI) of 244 fish and an upper 95% CI of 3,764 fish (Table 4). This was the lowest count on record during the 2008-2017 period.

Due to the recalculation of the aerial and ground counts, as well as the modifications to the observer efficiency and AUC models, the abundance estimates for all years tended to decrease from estimates reported in all earlier DDMMON-4 reports although there is still substantial overlap between the newly calculated AUC estimates and AUC estimates calculated using the previous AUC calculation method.

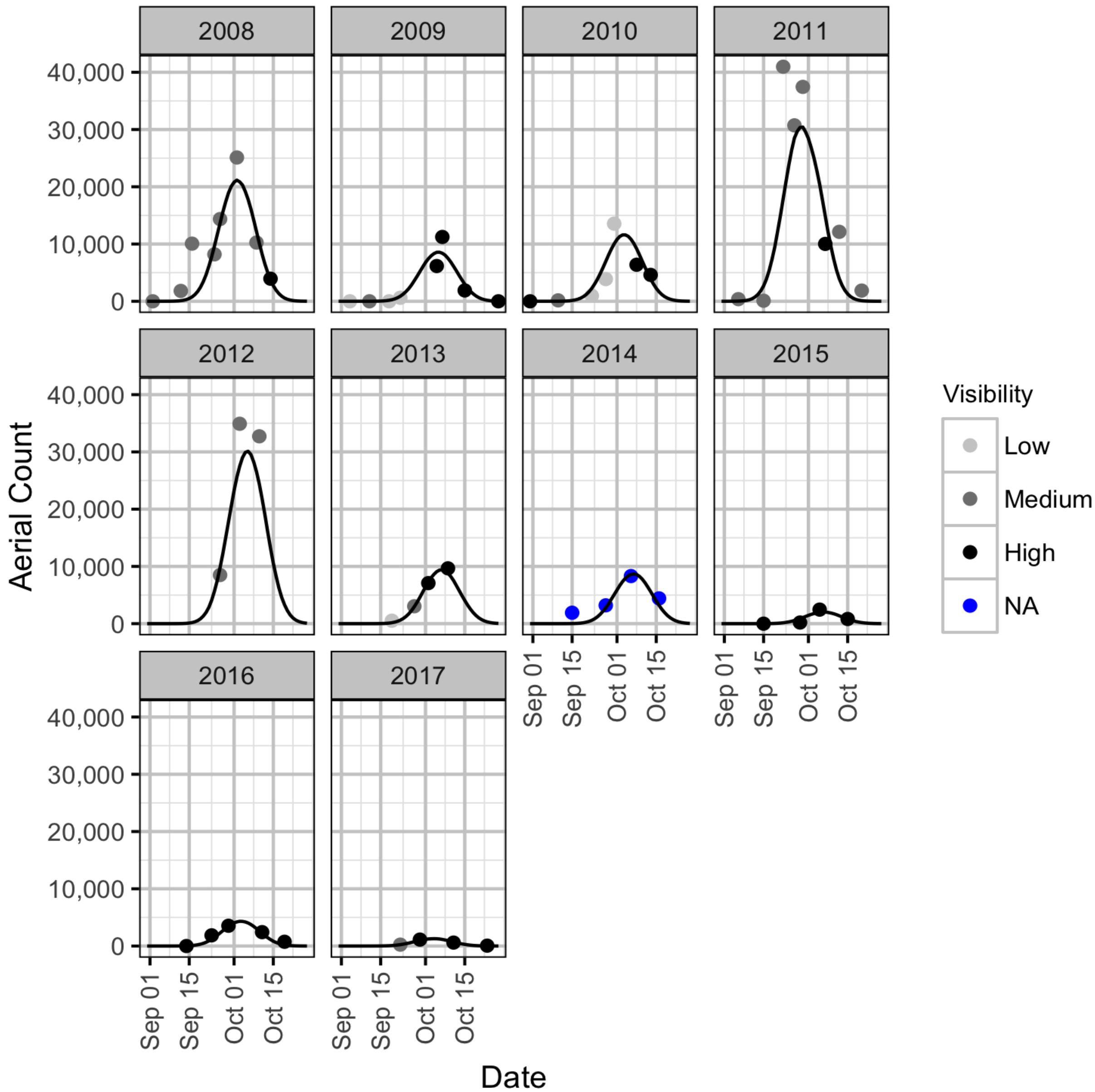


Figure 6: Kokanee spawner aerial counts (dots) with AUC estimated daily counts (black line) (gauged by low, medium and high visibility) by date and year within the LDR. Blue dots indicate visibility was not documented.

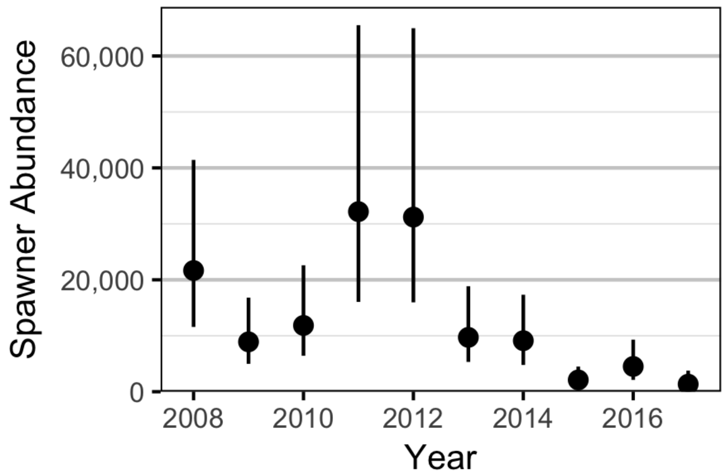


Figure 7: AUC estimated total LDR Kokanee spawner abundance by year with 95% CIs.

Table 4: AUC estimated peak Kokanee spawner abundance in the LDR from 2008–2017.

| Year | Total Spawner Abundance | Lower 95% CI | Upper 95% CI | # of Surveys |
|---|---|---|---|---|
| 2008 | 21,659 | 11,575 | 41,426 | 8 |
| 2009 | 8,910 | 4,979 | 16,813 | 8 |
| 2010 | 11,842 | 6,429 | 22,601 | 7 |
| 2011 | 32,182 | 16,057 | 65,504 | 8 |
| 2012 | 31,208 | 15,973 | 64,964 | 3 |
| 2013 | 9,712 | 5,327 | 18,846 | 4 |
| 2014 | 9,123 | 4,788 | 17,331 | 4 |
| 2015 | 2,104 | 725 | 4,488 | 4 |
| 2016 | 4,512 | 2,112 | 9,302 | 5 |
| 2017 | 1,349 | 244 | 3,764 | 4 |

## 3.4 Kokanee Peak Count Timing

The estimated timing of peak spawning abundance for LDR Kokanee in 2017 and throughout the rest of the DDMMON-4 project period from 2008–2016 is shown in Figure 8. A tabular summary for the timing of the estimated annual peak counts from 2008–2017 is also shown in Table 5. Peak spawning abundance was estimated for October 3 in 2017 which fell within the time range of peak spawning abundance observed in previous years.

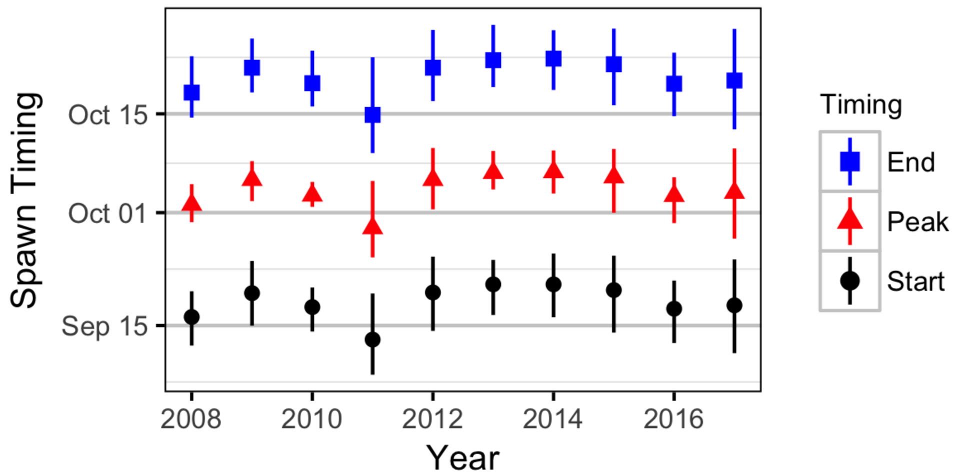


Figure 8: Predicted timing of LDR Kokanee spawning by sampling year with 95% CIs.

Table 5: Estimated timing of annual peak counts for Kokanee spawning by sampling year in the LDR study area.

| Year | Date of Peak Spawning | Lower 95% CI | Upper 95% CI |
|---|---|---|---|
| 2008 | Oct 2 | Sep 29 | Oct 4 |
| 2009 | Oct 5 | Oct 2 | Oct 8 |
| 2010 | Oct 3 | Oct 1 | Oct 5 |
| 2011 | Sep 28 | Sep 24 | Oct 5 |
| 2012 | Oct 5 | Oct 1 | Oct 9 |
| 2013 | Oct 6 | Oct 4 | Oct 9 |
| 2014 | Oct 6 | Oct 3 | Oct 9 |
| 2015 | Oct 6 | Oct 1 | Oct 10 |
| 2016 | Oct 3 | Sept 29 | Oct 6 |
| 2017 | Oct 3 | Sept 27 | Oct 9 |

### 3.5 Kokanee Emergence Timing

The Kokanee emergence timing was calculated based on the estimated spawn timing and the water temperature at DRL assuming 950 ATUs. The results are plotted below in Figure 9.

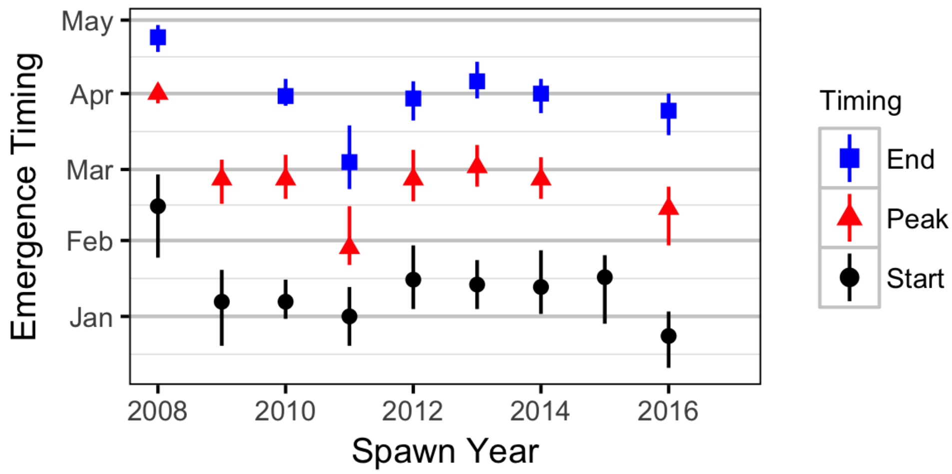


Figure 9: Predicted timing of LDR Kokanee emergence by spawn year with 95% CIs.

### 3.6 Relative Intensity of Kokanee Spawning in the Duncan River System

Total estimated number of spawning Kokanee for each location is presented in Figure 10. In 2017, the majority of the total estimated number of spawning Kokanee was from the Lardeau River (53%) while Meadow Creek contributed 36% and the LDR contributed 11% to the total estimated count (Figure 11, Table 6). Estimated spawner abundance distribution in 2017 was similar to previous years, when Kokanee escapement to Meadow Creek and Lardeau River represented >88% (2015, 2016) and >94% (2008-2014) of the total Duncan system Kokanee run; however, contribution from Meadow Creek Spawning Channel was higher than Lardeau River in earlier monitoring years (Figure 11, Table 6).

The combined Kokanee escapement estimate for all three segments of the Duncan system in 2017 (11,988) was the lowest on record and represents 0.7% of the largest escapement estimate of 1,796,073 Kokanee in 2011 (Figure 12, Table 6).

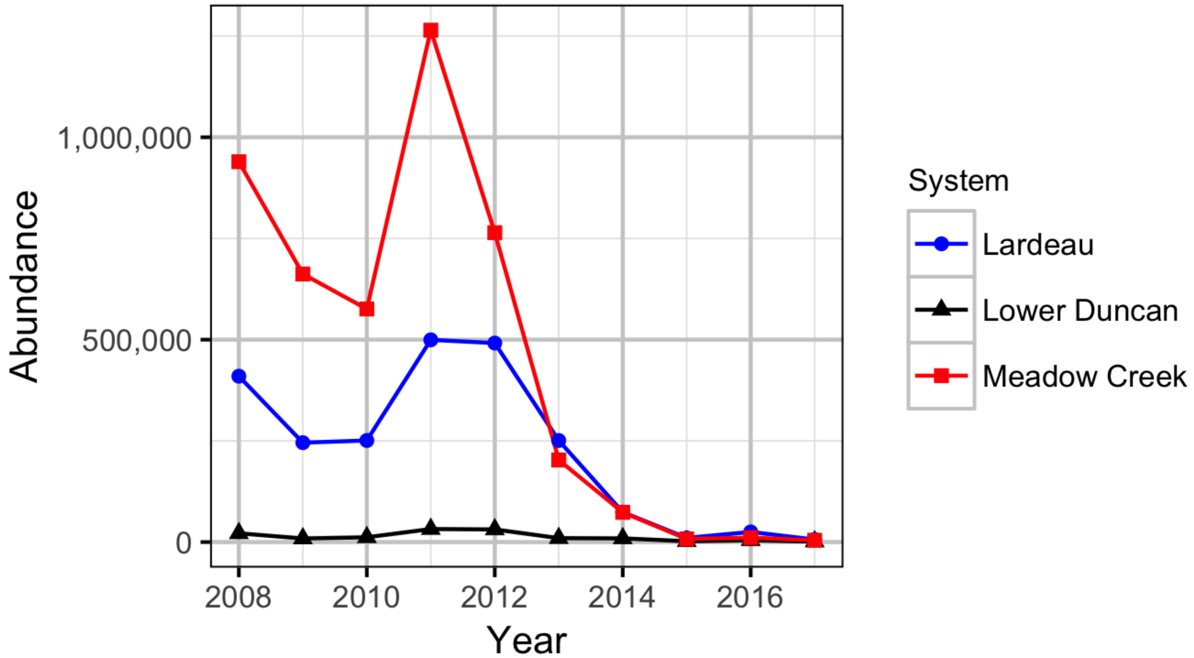


Figure 10: Total estimated number of Kokanee spawning in Meadow Creek, Lardeau River, and the Lower Duncan River, 2008-2017 (source for Meadow Creek and Lardeau River: MFLNRO, M. Neufeld pers. comm./unpublished data; source for Lower Duncan River: AMEC 2013; Zimmer et al. 2015; Zimmer et al. 2016, Plate et al. 2016, Zimmer et al. 2017).

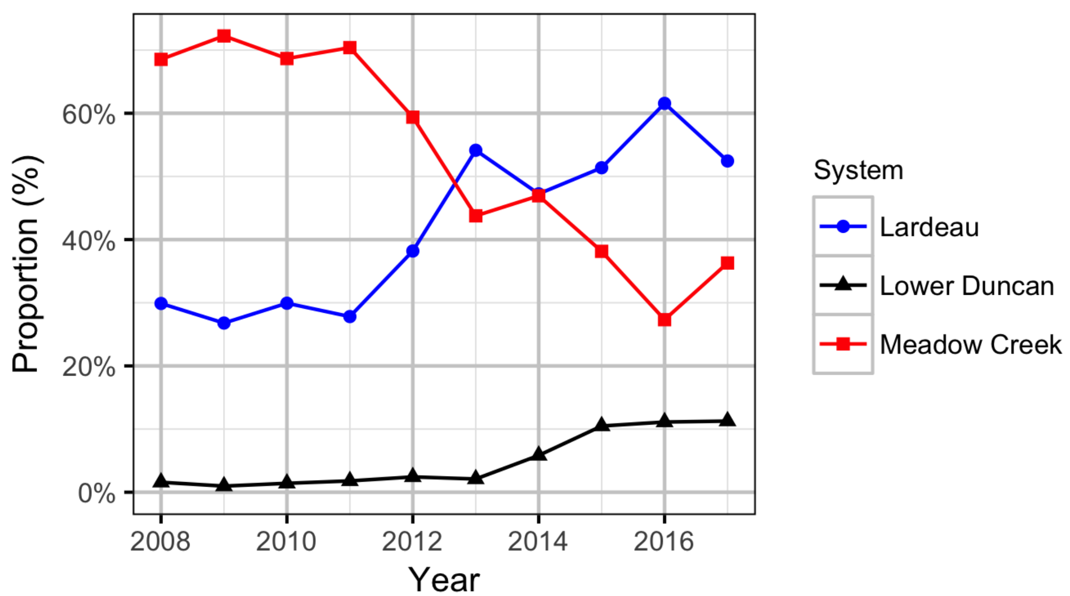


Figure 11 Estimated percentage of Kokanee spawning in Meadow Creek, Lardeau River, and theLower Duncan River, 2008-2017 (source for Meadow Creek and Lardeau River: MFLNRO, M. Neufeld pers. comm./unpublished data; source for Lower Duncan River: AMEC 2013;Zimmer et al. 2015; Zimmer et al. 2016, Plate et al. 2016, Zimmer et al. 2017).

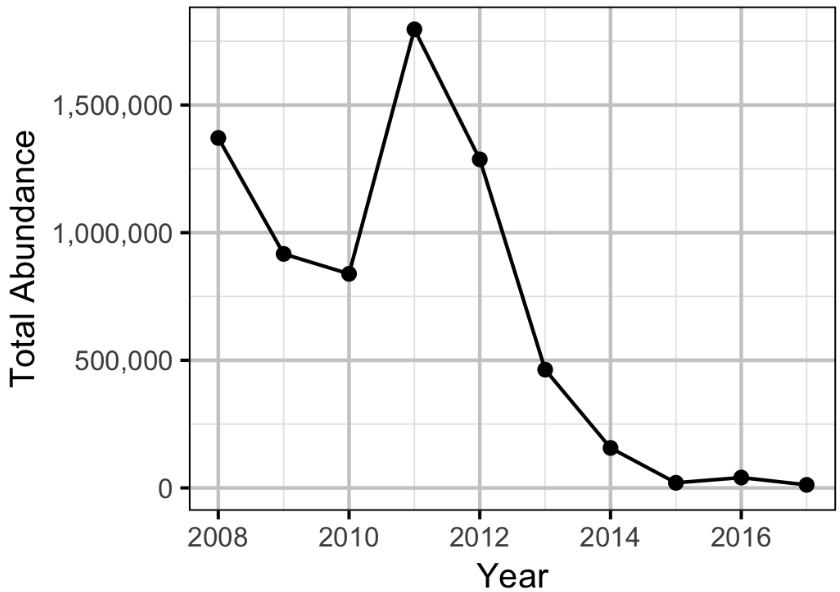


Figure 12 Estimated combined total abundance of Kokanee spawning in Meadow Creek, Lardeau River, and the Lower Duncan River, 2008-2017 (source for Meadow Creek and Lardeau River: MFLNRO, M. Neufeld pers. comm./unpublished data; source for Lower Duncan River: AMEC 2013; Zimmer et al. 2015; Zimmer et al. 2016, Plate et al. 2016, Zimmer et al. 2017).

Table 6: Relative intensity of estimated Kokanee spawning abundance in the whole Duncan River system, 2008-2017.

| Year | Meadow Creek (%) | Lardeau River (%) | Lower Duncan River (%) | Total Estimate |
|---|---|---|---|---|
| 2008 | 68% | 30% | 2% | 1,371,020 |
| 2009 | 72% | 27% | 1% | 916,579 |
| 2010 | 69% | 30% | 1% | 838,666 |
| 2011 | 70% | 28% | 2% | 1,796,073 |
| 2012 | 60% | 38% | 2% | 1,286,791 |
| 2013 | 44% | 54% | 2% | 463,246 |
| 2014 | 47% | 47% | 6% | 156,387 |
| 2015 | 38% | 51% | 10% | 20,029 |
| 2016 | 27% | 62% | 11% | 40,473 |
| 2017 | 36% | 53% | 11% | 11,988 |

### 3.7 Migration, Holding and Spawning Behaviour

In 2017, all Kokanee throughout all four surveys were observed to be spawning (Figure 13). This differed from other years when Kokanee were found to be migrating or holding during early surveys as was the case on September 13 and September 22, 2016. No dead Kokanee were observed in 2017.

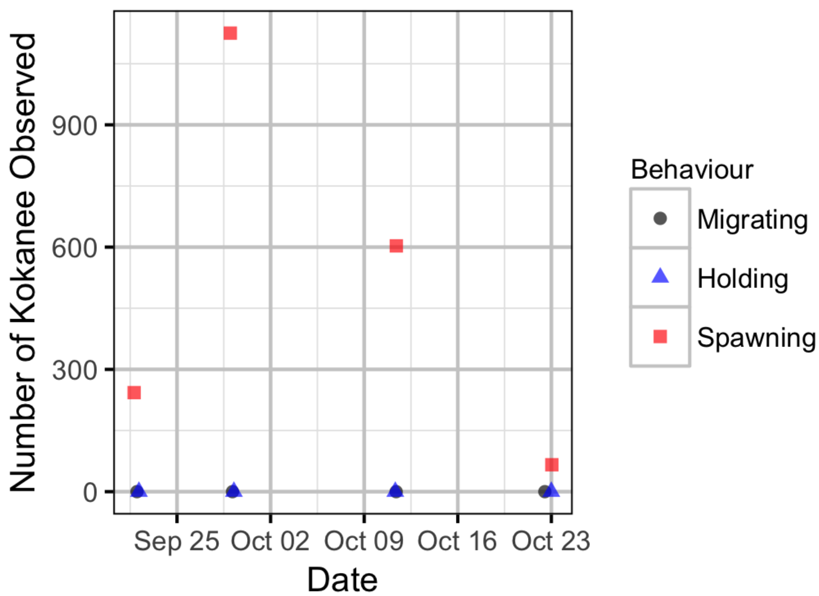


Figure 13: Number of migrating, holding and spawning Kokanee enumerated in the Lower Duncan River in 2017.

### 3.8 Spawner Distribution and Habitat Use in the LDR

In general, very few Kokanee were observed spawning in LDR side channels in 2017 during the first two flights and no fish were observed in side channels after that (Table 7).

As in previous years, Kokanee were observed to spawn between Kilometers 1.4 and 9.6 (See Appendix A). No redds were observed upstream of Kilometer 1.4 from Duncan Dam which is the upstream end of the study reach, or from Kootenay Lake (downstream end of the study reach) to River km (Rkm) 9.5. Most notable concentrations of spawning Kokanee in 2017 were found between Rkm 1.5-3.1 where 70% of the spawning Kokanee within the study reach were observed. Side channel (SC) use for spawning in 2017 was observed pre-flow reduction on September 22 in SC 1.1R (68 fish) and in SC 4.1R and SC 4.4R post-flow reduction on September 29 (42 fish) (See Appendix A).

Table 7: Number of observed spawning Kokanee distributed in the LDR main stem and side channels for 2017.

| Date | Main Stem (MS) or Side Channel (SC) | Holding (N) | Migrating (N) | Spawning (N) |
|---|---|---|---|---|
| 22-Sep-16 | MS | 0 | 0 | 175 |
| | SC | 0 | 0 | 68 |
| 29-Sep-16 | MS | 0 | 0 | 1105 |
| | SC | 0 | 0 | 42 |
| 11-Oct-16 | MS | 0 | 0 | 603 |
| | SC | 0 | 0 | 0 |
| 23-Oct-16 | MS | 0 | 0 | 66 |
| | SC | 0 | 0 | 0 |

## 3.9 Kokanee Potential Egg Deposition, Egg Losses and Effectiveness of Flow Reductions

The 2017 Kokanee spawning locations in the LDR were mapped on a series of six maps attached as Appendix A. Redd mapping was based on redd surveys conducted on September 22, September 29, October 11 and October 23, 2017. Potential egg deposition and egg losses were calculated from area calculations based on the comparative redd distributions between side channel and main stem habitats before and after flow reductions, starting from 231 $m^3$/s on September 23; down to 178 $m^3$/s on September 24 and further reduced to 96 $m^3$/s on September 25, 2017.

The total area used by spawning Kokanee pre-flow reduction in the LDR in 2017 was 4,258 $m^2$ in the mainstem and 154 $m^2$ in the side channels for a total combined area of 4,412 $m^2$. In 2017, this total spawning area was estimated to contain 26,852 eggs (243 fish / 2 = 121.5 females x 221 eggs/female) (AMEC fecundity estimate) or 87,480 eggs (243 fish / 2 = 121.5 females x 720 eggs/female) (MFLNRO fecundity estimate) that were deposited (Table 8; see Section 2.5.4 for formulae) before the flow reduction. Of those 26,852 eggs, 7,514 eggs were deposited in the side channels, while 19,338 were deposited in the main stem for the AMEC fecundity estimate of 221 eggs per female. Based on the 2017 MNFLNRO fecundity estimate of 720 eggs per female, 24,480 eggs were deposited in the side channels and 63,000 eggs were deposited in the mainstem. No loss in spawning area was observed in 2017 in the side channels as a consequence of the flow reduction. Therefore, the calculated egg loss based on flow reduction was 0 eggs. The same was true for the main stem were no loss of spawning area was observed in 2017and therefore no egg losses occurred. Egg deposition in mainstem redds before the flow reduction was 5 eggs / $m^2$ (19,338 eggs / 4,258 $m^2$) based on AMEC fecundity estimate and 15 eggs/$m^2$ (63,000 eggs / 4,258 $m^2$) based on FLNRO 2017 fecundity estimates.

Table 8: Total Kokanee spawning area pre-flow reduction, area dewatered (difference) post flow reduction, Potential Egg Deposition (PED) pre-flow reduction, number of eggs dewatered (difference) from pre-flow reduction for side channel (SC) and main stem areas (MS) within the LDR study area from 2009 to 2017 (adapted from AMEC 2013, Zimmer et al. 2015, Zimmer et al. 2016, Plate et al. 2016, Zimmer et al. 2017). AMEC=1 or FLNRO=2 denotes different fecundity estimates as described in previous sections.

| Year | Pre- or Post Flow Reduction | Total Spawning Area ($m^2$) | | Potential Egg Deposition (N) | |
|---|---|---|---|---|---|
| | | Side Channel | Main Stem | Side Channel | Main Stem |
| 2017 | Pre | 154 | 4,258 | 7,514 (1); 24,480 (2) | 19,338 (1); 63,000 (2) |
| Flows: | Post | 154 | 4,258 | 7,514 (1); 24,480 (2) | 19,338 (1); 63,000 (2) |
| 231-96 $m^3/s$ | Difference | 0 | 0 | 0 | 0 |
| 2016 | Pre | 185 | 13,564 | 3,757 (1); 13,073 (2) | 202,989 (1); 706,327 (2) |
| Flows: | Post | 179 | 13,564 | 3,635 (1); 12,648 (2) | 202,989 (1); 706,327 (2) |
| 240-100 $m^3/s$ | Difference | 6 | 0 | 122 (1); 425 (2) | 0 |
| 2015 | Pre | 1,118 | 14,857 | 19,148 | 254,450 |
| Flows: | Post | 1,118 | 14,857 | 19,148 | 254,450 |
| 250-72 $m^3/s$ | Difference | 0 | 0 | 0 | 0 |
| 2014 | Pre | 2,795 | 12,847 | 297,332 | 1,366,664 |
| Flows: | Post | 2,755 | 12,825 | 293,077 | 1,364,324 |
| 244-75 $m^3/s$ | Difference | 40 | 22 | 4,255 | 2,340 |
| 2013 | Pre[a] | 1,078 | 1,739 | 168,623 | 1,025,771 |
| Flows: | Post | 936 | 1,739 | 146,449 | 1,025,771 |
| 245-92 $m^3/s$ | Difference | 142 | 0 | 22,173 | 0 |
| 2012 | Pre[b] | 4,734 | N/A | 473,172 | 2,713,272 |
| Flows: | Post[c] | 3,973 | 20,922 | 397,156 | 2,713,272 |
| 242-75 $m^3/s$ | Difference | 760 | 0 | 76,016 | 0 |
| 2011 | Pre | 6,902 | 88,172 | 3,253,621 | 2,372,672 |
| Flows: | Post | 5,902 | 88,172 | 2,781,955 | 2,372,672 |
| 248-74 $m^3/s$ | Difference | 1,000 | 0 | 471,666 | 0 |
| 2010 | Pre | 4,041 | 8,055 | 830,540 | 642,948 |
| Flows: | Post | 3,784 | 8,632 | 777,601 | 640,852 |
| 245-75 $m^3/s$ | Difference | 258 | -577 | 52,939 | 2,096 |
| 2009 | Pre | 399 | 0 | 48,732 | - |
| Flows: | Post[d] | 267 | 4219 | 32,667 | - |
| 215-73 $m^3/s$ | Difference | 132 | - | 16,065 | - |

[a] Based on back calculating areas based on observed watered and dewatered side channel and main stem redds on one survey – October 2, 2013

[b] Main stem mapping was not conducted prior to the flow reduction. However, no dewatered redds were observed in the main stem during post-reduction mapping.

[c] Additional spawning areas were observed post-reduction (3556 $m^2$) because Kokanee moved into side channels but the information presented reflects the original spawning area dewatered and changes to PED.

[d] Larger area was observed post-reduction because Kokanee moved into side channels to spawn. Only 132 $m^2$ of area was dewatered from the original pre-reduction mapping, which is reflected in PED.

- Spawning was not observed pre-reduction. It was assumed that post-reduction spawning areas were not dewatered.

### 3.10 Side-Channel Dewatering and Discharge

In 2017, the state of flow through all LDR side channels was monitored for all four survey dates (Table 9). Before the flow reduction on September 24, all side channels were flowing at their inlet and outlet. Following the flow reduction, from September 29 – October 23 flow through side channels 1.1R, 3.5R and 6.9R was completely cut off from the mainstem while inlet cut off and outlet backwatering from the mainstem was observed for side channel 7.6R. Flow through side channels 2.7L, 4.4R, 8.2L and 8.8L was reduced by the flow reduction but was still connected at the inlet and outlet to the mainstem.

Table 9 Summary table for the state of flow in the LDR side channels for the four 2017 survey dates (ON = both inlet and outlet flowing; BW = Inlet cut off – Outlet wetted with backwatering from mainstem; OFF = Inlet and outlet cut off from mainstem – may contain isolated pools).

| Side Channel | Date: (dd/mm/yy) | | | |
|---|---|---|---|---|
| | 22/09/17 | 29/09/17 | 11/10/2017 | 23/10/17 |
| 1.1R | ON | OFF | OFF | OFF |
| 2.7L | ON | ON | ON | ON |
| 3.5R | ON | OFF | OFF | OFF |
| 4.1R | ON (now main channel) | ON (now main channel) | ON (now main channel) | ON (now main channel) |
| 4.4R | ON | ON | ON | ON |
| 6.9R | ON | OFF | OFF | OFF |
| 7.6R | ON | BW | BW | BW |
| 8.2L | ON | ON | ON | ON |
| 8.8L | ON | ON | ON | ON |
| Disharge ($m^3/S$) Station 08NH118-BC | 228 | 91 | 92.7 | 94.4 |

### 3.11 Argenta Slough

As part of the 2017 LDR surveys, BC Hydro requested photographs and a summary paragraph on the current condition of Argenta Slough located on the west side of the LDR downstream end and the LDR mouth into Kootenay Lake.

The overflight of this area was carried out on September 22, 2017 when the photographs shown in Figure 14 were taken. Argenta slough appears to be ecologically healthy and act as wetland that is connected to the LDR through a channel that has accumulated a considerable volume of Large Woody

Debris (LWD) at its confluence with the LDR, which can be clearly seen in the left panel of Figure 14. More pictures of the upstream end of Argenta Slough will be provided to BC Hydro upon request.

Figure 14: Pictures of Argenta Slough connection with the LDR (left picture) and overview of the slough upstream of the connection with the LDR (right picture) close to its mouth into Kootenay Lake. In the right picture the LDR can be seen on the left side and Argenta Slough on the right (pictures taken on September 22, 2017).

# 4.0 DISCUSSION

## 4.1 Lower Duncan River Environmental Parameters: Temperature and Discharge

Water temperatures followed a similar trend to previous years showing a correlated decrease following the decrease in discharge. This pattern was very similar to the pattern observed in 2014 and 2015, when, following a small (+1 °C) increase in water temperature from September 15-30, water temperature decreased steadily throughout the spawning period in the LDR. Similar trends of decreasing water temperatures throughout the main spawning period were observed since 2009, and ranged from 16 °C to 8 °C (AMEC 2012, 2013, no data recorded in 2008). Temperature reductions are primarily based on reductions in DDM discharge, thereby decreasing inflows from the warmer reservoir and receiving more influence from the colder and natural flow contribution of the Lardeau River. This may also explain the slight increase in temperature at the onset, coincident with higher DDM discharge. It is believed that reducing the proportion of DDM discharge to the Lower Duncan River reduces the temperature in the fall (AMEC and Poisson 2012). Results of DDMMON7 also found LDR water temperatures to be higher during incubation and emergence life stages (October through January) influencing development and promoting earlier timing of emergence compared to the Lardeau River (AMEC and Poisson 2012).

Lower Duncan River discharge was regulated through DDM in consideration of Lardeau River flows in September and October 2017 to manage for protection of Kokanee spawning in the LDR. In 2017 as in 2016 and 2013, Kokanee protection flows were initiated on September 24, 3-4 days earlier than typical for the other seven study years and discharge was reduced in a two-step pattern from summer highs (>210 $m^3$/s) down to around 90-100 $m^3$/s. From 2008-2012 and in 2014, discharge was also reduced in a two-step pattern starting from the same summer highs but to lower flows of 70-76 $m^3$/s. For all years except 2015 reduced flows stayed at the same level throughout the spawning period until the beginning of November. In 2015, flows were reduced from >210 $m^3$/s to 70-76 $m^3$/s but were then increased back to flows >210 $m^3$/s on October 22.

The minimum Kokanee protection flow increase from 72-76 $m^3$/s from 2008-2012 and in 2014 and 2015 to the increased minimum flow of 95-100 $m^3$/s in 2013, 2016 and 2017 combined with the earlier timing of the flow reduction has likely led to less loss of Kokanee spawning habitat, redds and eggs since and earlier onset reduced the chance of fish to spawn in areas that may become dewatered later and higher minimum flows kept more area inundated.

## 4.2 Spawn Run Timing

The initial spawning survey took place on September 22, 2017 with 243 Kokanee observed spawning within the main stem LDR and in the SC at the confluence with the Lardeau River. Likely due to the later first flight in 2017, no Kokanee were observed holding on September 22, 2017 because all fish were already spawning. In 2015 and 2016 large numbers of Kokanee were observed holding at the Lardeau – LDR confluence in mid-September surveys likely bound for the Lardeau River. The September 22, 2017 survey was concurrent with higher Duncan Dam discharges preceding the initiation of annual discharge reductions for Kokanee spawning protection. The highest visual count of 1,147 Kokanee was observed on the second enumeration flight on September 29, 2017, which was the same date for the highest count in 2016 and earlier than the dates of the flights with the highest observed counts in 2015 (2,458 on October 5), 2014 (peak of 8,315 on October 6) and 2013 (peak of 9,662 on October 9). However, between 2002 and 2011 dates of the highest number of fish observed in an aerial survey have ranged from September 19 to October 7 (AMEC 2013). Peak count dates do not represent the estimated peak of the run but are the highest count observed in an aerial survey which likely does not represent the date that the run was estimated to peak at.

Continued surveys indicated an increase in the number of spawning Kokanee in the LDR from September 22 (first survey), to the peak count on the second survey (September 29), followed by a significant decrease to 603 fish on the third survey (October 11) and 66 fish on the final survey on October 23. This trend is consistent with observations from annual Kokanee enumerations conducted by MFLNRO throughout the Kootenay and Arrow Lakes regions. In general, Kokanee spawning in the LDR starts in the third week of September, peaks during the first week of October and ends during the third and fourth week of October. Therefore, the earlier onset of flow reduction on September 24 in 2016 and 2017 coincide better with the onset of spawning but likely the onset of the flow reduction to an earlier date around September 15 would have an even larger impact on the avoidance of egg loss though dewatering. This is especially true for years with high spawner abundances when more side channels and peripheral areas of the mainstem are used for spawning. In years of low spawner abundance such as, 2015-2017 little to no side channels or peripheral areas in the mainstem are used for spawning. The start of spawning in most years preceded the flow reduction and thus the flow reduction and related changes in water temperature, neither appear to represent a migration timing cue into the LDR nor a spawn timing cue.

## 4.3 Area Under the Curve Estimates

Using a model that was revised in 2016, for Area Under the Curve (AUC) estimation, the 2017 Kokanee spawning population in the LDR was estimated to be 1,361 fish (95% CI: 313 – 3,592). In comparison to previous years, the 2017 estimate is the lowest on record and the continuation of a downward trend. The highest spawner abundance estimates of 31,973 occurred in 2011 (Lower CI = 16,820; Upper CI = 60,928). Similarly, in 2017 the lowest combined escapement estimate of 11,988 Kokanee for all three segments of the Duncan system (Meadow Creek, Lardeau River and LDR) was recorded. The 2017 combined estimate represented only 0.7% of the largest combined escapement estimate of 1,796,073 Kokanee in 2011.

In 2016, the Area Under the Curve (AUC) model was modified so that the uncertainty varied with the annual spawner abundance. The refinement reduced the uncertainty around the abundance estimates particularly for years with lower counts. The reduction in uncertainty combined with the changes in observer efficiency resulted in substantially lower estimates of abundance which were nonetheless within the range of possible values from previous analyses. The reduction in uncertainty is considered an improvement because it accounts for the fact that the variation in abundance is greater in years with more fish.

## 4.4 Relative distribution of Kokanee spawners in the Lower Duncan River

In 2017, Kokanee were observed to spawn between Rkm 9.5 at the downstream end of the LDR, close to Kootenay Lake and Rkm 1.4 at the upstream end of the LDR close to Duncan Dam. Most notable concentrations of spawning Kokanee in 2017 were found between Rkm 1.5-3.1 where 70% of the spawning Kokanee within the study reach were observed. These main concentrations of redds were observed in areas where substrate composition (gravel) and flow (estimated between 0.3-0.8 m/s) appeared ideal for Kokanee spawning. Many areas that also provided spawning habitat characteristics were not used in 2017 due to the low overall number of fish. The general spawning utilization of side-channels, even those that have only a slightly lower flow than the main channel, just like the overall number fish observed, was reduced when compared with previous years and limited to small sections of SCs 1.1R, 4.1R and 4.4R pre- and post-flow reduction (see Appendix A). No use of side channels with surface flow that was stopped as a consequence of the flow reduction was observed in 2017. It appears as if fish that are spawning in side channels with loss of surface flow during flow reduction may be decreasing in numbers over time likely based on the complete loss of their offspring by dewatering.

## 4.5 Relative Intensity of 2017 Kokanee Spawning in the LDR

From 2008-2012, the majority (60-72 %) of Kokanee in the Duncan River watershed used to spawn in Meadow Creek Spawning Channel. From 2013 on, along with decreasing total estimated run sizes, this picture changed and the majority of Kokanee in the system spawned in the Lardeau and the LDR combined. In 2015, 2016 and 2017, an estimated total of less than 41,000 fish spawned in all three spawning spawning tributaries of the Duncan system and due to the low numbers of spawners in the Meadow Creek Spawning Channel, the relative contribution of the LDR spawning rose from 1 % in 2009 to 11 % in 2016 and 2017 while contribution of the Lardeau River stayed high at 53% and contribution of the Meadow Creek Spawning Channel stayed again far below historic highs at 36%. These numbers should be viewed in the context that total Kokanee escapement to the three monitored spawner areas has undergone significant and dramatic decline since 2012.

## 4.6 Kokanee Spawn Mapping, PED and Egg Losses

The total area used by spawning Kokanee pre-flow reduction in the LDR mainstem in 2017 was approximately 4,412 $m^2$ or the smallest area recorded as part of DDMMON-4. In 2017, this spawning area was estimated to contain 26,852 eggs (AMEC fecundity estimate) or 87,480 eggs MFLNRO fecundity estimate) that were deposited before the flow reduction. There was no loss in spawning area in 2017 in the side channels as a consequence of the flow reduction. Therefore, egg loss due to flow reduction did not appear to have occurred in 2017. However, the low use of side channels may be a result of a continued drastic decrease in spawner escapement.

Historically, side channel usage is highest at the start of the run prior to the Kokanee protection flows being implemented, as Kokanee seek low velocities for spawning. Once flows are reduced, main stem habitats are more abundant and preferred (AMEC 2013). As in 2016, the main stem of the LDR was the preferred spawning habitat in 2017, as only 110 or 5.6% of the total number of 1,946 Kokanee observed in aerial surveys spawned in side channels and these side channels stayed inundated post flow reduction. It is therefore not surprising that no dewatered redds were observed in 2017 and there was no evidence of egg loss due to flow reductions in 2017.

Earlier DDM flow reductions in 2017, 2016 and 2013 for Kokanee spawning protection appeared to be conclusive with regards to lowering the loss of eggs due to dewatering but it appears that the very low total escapement of Kokanee to the LDR also played a significant role in the reduction of egg loss by dewatering. Recent observations in reduction of side channel use could be a result of reducing flows earlier, providing ideal spawning conditions in the mainstem rather than using side channels. Alternatively, spawning area use in years of escapement of <1,500 fish (2017) should not be compared to years of escapement <32,000 fish. Twenty-two times more fish will use a lot more spawning area which is limited in the LDR and thus side channel use is more likely in years of high escapement than in years of very low escapement.

For overall PED, consideration should also be given to the apparent increase in individual Kokanee fecundity. In 2015, fish size appeared to be larger, an observation confirmed again in 2016 and in 2017 with visual observations from the both, DDMMON 4 air and ground crews. Air crews cited that individual fish were more discernable in 2016 and 2017. Meristic data collected by FLNRO at the MCSC confirm our observations of uniformly larger fish in 2016. FLNRO 2016 MCSC average length (FL) for female spawner kokanee was 38.0 cm, compared to 24.1 cm (AMEC 2009) and 20.0-25.0 cm (AMEC 2012). Similarly, 2017 fecundity data also collected by FLNRO showed a three-and-a-half times increase in egg deposition per female compared to AMEC's findings from 2012-2013. Given the prolonged decline in Kokanee escapement to the Duncan/Lardeau system from Kootenay Lake, there exists an opportunity for greater annual growth with the significant decrease in inter-cohort competition (Rieman and Myers 1992), and the response appears to be a larger average fish size at maturation and spawning. It should be noted however, that increased size at maturity and subsequent increase in fecundity since 2015 does not make up for the drastic decline in Kokanee escapement to the entire LDR study area.

## 4.7 Discussion of Management Questions without Data Collection in 2017

### 4.7.1 Kokanee Spawner Distribution Meadow Creek

Based on previous studies (AMEC 2012), the majority of spawning occurs in the 3 km of Meadow Creek Spawning Channel (located approximately 4 km upstream of the confluence with the Lower Duncan River) with idealized conditions (clean gravel and constant flows) for Kokanee egg incubation. Meadow Creek reaches outside of the spawning channel are mainly used when the spawning channel itself is filled to capacity with Kokanee spawners (AMEC 2012). The substrate of the lower section of Meadow Creek has a high percentage of silt and fewer spawning gravels and is therefore limited in suitability for Kokanee spawning (Quamme 2008). Access to suitable spawning habitat upstream of the spawning channel is blocked by a waterfall barrier approximately 2 km upstream of the spawning channel.

### 4.7.2 Kokanee Spawner Distribution Lardeau River

Based on previous studies (AMEC 2012), Kokanee spawning in the Lardeau River has been observed along its whole length with the highest densities found in the upriver side channels. Spawning suitability along the whole length of the Lardeau River is likely aided by its natural hydrograph, with typical spring flush flows that remove fines from spawning gravel (AMEC 2013) throughout its entire length.

### 4.7.3 Kokanee spawning timing and Kokanee morphology between spawning runs in the Lower Duncan River, Lardeau River and Meadow Creek for consideration of future decisions.

Peak spawning in the Lardeau River and in the Meadow Creek Spawning Channel was observed to occur in the last week of September and the mid of September, respectively. These peak spawning periods are earlier than the peak spawning observed in the LDR in the first week of October although genetic differences between the three spawning populations within this system do not appear to exist (AMEC 2012; Lemay and Russello 2012). Therefore, the timing differences in peak spawning between the three spawning locations are not likely based on genetic predisposition but more likely on environmental cues. Given that the Duncan Dam Low Level Discharge from below the thermocline moderates water temperature in the LDR in providing lower than natural surface water temperatures in the summer and higher than natural surface water temperature in the winter, the peak spawn timing differences may be based on water temperature. Results of DDMMON7 suggest peak spawning is influenced by water temperature with kokanee spawning later in the LDR due to warmer water temperatures in early September compared to Meadow Creek and Lardeau River (AMEC and Poisson 2012).

### 4.7.4 What physical works or operational constraints could be implemented to minimize operational conflicts associated with recommended Kokanee spawning operations?

Annual Kokanee spawner protection flows dewater most side channels during the beginning of the Kokanee spawning period and therefore appear to keep Kokanee from spawning in side channels in years of low total escapement (<5,000 fish) such as 2015-2017. In these low escapement years, total egg losses in side channels are very small or do not exist. Despite Kokanee protection flows, albeit to 75 $m^3/s$ rather than 95-100 $m^3/s$ in years of high escapements (>30,000 fish) such as 2011 and 2012, egg losses in side channels were much larger with 471,666 and 76,016 eggs lost, respectively. To reduce the potential of side channel red dewatering even more, flow reduction could be started even earlier on or around the September 15 date and before the onset of spawning to minimize egg loss during years of high and low escapement. In general, it is recommended that the DDM Works 4 program *("Action Plan to Minimize Risk of Stranding Spawning Kokanee")* utilize the information gathered in this monitoring program to evaluate alternatives that minimize impacts to the early Kokanee spawning run, in consideration of operating agreements (Columbia River Treaty, International Joint Commission) and other Water Use Plan objectives (flood control and recreation). The outcome of this analysis would be used to inform future Water Use Plan review processes on opportunities that minimize stranding while accommodating other important water use objectives.

## 5. REFERENCES

Acara, A.H. 1970. The Meadow Creek Spawning Channel. Unpublished Report. Fish and Wildlife Branch, Victoria, BC.

AMEC. 2009. Lower Duncan River Kokanee Spawning Monitoring (DDMMON-4) - Year 1 Data Report (2008). DDMMON#4. Prepared for BC Hydro – Kootenay Generation Area, Castlegar, B.C. 37 pp + 5 App.

AMEC. 2010. Lower Duncan River Kokanee Spawning Monitoring (DDMMON-4) – Year 2 Data Report (2009). Prepared for BC Hydro – Castlegar, BC. 43 p. + 7 App.

AMEC. 2011. Lower Duncan River Kokanee Spawning Monitoring (DDMMON-4) – Year 3 Report (2010). Prepared for BC Hydro – Castlegar, BC. 35 p. + 4 App.

AMEC. 2012. Lower Duncan River Kokanee Spawning Monitoring (DDMMON-4) - Year 4 Synthesis Report. Report Prepared for: BC Hydro, Castlegar. Prepared by: AMEC Environment & Infrastructure Ltd. 60 pp + 8 App.

AMEC. 2013. Lower Duncan River Kokanee Spawning Monitoring (DDMMON-4) - Year 5 Synthesis Report. Report Prepared for: BC Hydro, Castlegar. Prepared by: AMEC Environment & Infrastructure Ltd. 22 pp + 2 App.

AMEC and Poisson. 2012. Lower Duncan River Water Quality Monitoring (DDMMON-7): Year 2 Report. Prepared for BC Hydro – Kootenay Generation Area, Castlegar, B.C. 51 pp. + 4 App.

BC Hydro. 2004. Consultative Committee Report, Duncan Dam Water Use Plan – Executive Summary. Prepared by the BC Hydro Project Team and Duncan Dam Water Use Plan Consultative Committee. 10 pp.

BC Hydro. 2007. Duncan Dam Project Water Use Plan. December 20, 2007. Prepared for the BC Hydro Duncan Dam Water Use Plan Project, Burnaby, B.C.

BC Hydro. 2008. Duncan Dam Water Use Plan Monitoring Program Terms of Reference.

English, K. K., Bocking, R. C., and Irvine, J. R. 1992. A robust procedure for estimating salmon escapement based on the area-under-the-curve method. Canadian Journal of Fisheries and Aquatic Sciences. 49(10):1982–1989.

Hilborn, R., Bue, B., and Sharr, S.1999 Estimating spawning escapements from periodic counts: a comparison of methods. Canadian Journal of Fisheries and Aquatic Sciences. 56(5): 888-896.

Kéry, M., Michael Schaub.2011. Bayesian population analysis using {WinBUGS} : a hierarchical perspective. Available: http://www.vogelwarte.ch/bpa.html

Lemay, M.A. and M.A. Russello. 2012. Neutral loci reveal population structure by geography, not ecotype, in Kootenay Lake kokanee. North American Journal of Fisheries Management 32: 282-291.

McElreath, R. 2016. Statistical rethinking: a Bayesian course with examples in R and Stan. CRC Press/Taylor & Francis Group, Boca Raton.

Morbey, Y.E., and Ydenberg, R.C. 2003. Timing games in the reproductive phenology of female Pacific salmon (Oncorhynchus spp.). The American Naturalist **161**(2): 284–298.

Rieman, B.E. and Myers, D.L. 1992. Influence of fish density and relative productivity on growth of Kokanee in ten oligotrophic lakes and reservoirs in Idaho. Transactions of the American Fisheries Society 121, 178-191.

Plate, E., M. Zimmer, and J. Thorley. 2016. Lower Duncan River Kokanee Spawning Monitoring (DDMMON-4) - Year 8 Data Report. Report Prepared for: BC Hydro, Burnaby. Prepared by: Okanagan Nation Alliance and LGL Limited. 39 pp + 1 App.

Plummer, M. 2012. {JAGS} version 3.3.0 user manual. Available: http://sourceforge.net/projects/mcmc-jags/files/Manuals/3.x/.

R Team.2013. R: a language and environment for statistical computing. Available: http://www.R-project.org.

Quamme, D. 2008. Meadow Creek Spawning Channel - Scarification Monitoring and Suspended Sediment Assessment 2003-2007. Prepared for Fish and Wildlife Compensation Program, Nelson, BC Prepared by Integrated Ecological Research, Nelson, BC. 26 pp + 7 app.

Quinn, T.P. 2005. Behavior and Ecology of Pacific Salmon and Trout. ISBN 0-7748-1127-7. American Fisheries Society – UBC Press. 378 pp.

Su, Z., Adkison, M, and Alen, B. 2001. A hierarchical Bayesian model for estimating historical salmon escapement and escapement timing. Canadian Journal of Fisheries and Aquatic Sciences. 58(8):1648-1662.

Thorley, J. 2014. jaggernaut: An R package to facilitate Bayesian analyses using JAGS (Just Another Gibbs Sampler). Available: https://github.com/joethorley/jaggernaut.

Wickham, H. 2009 ggplot2: elegant graphics for data analysis. Available: http://had.co.nz/ggplot2/book.

Zimmer, M., C. K. Whitney, J. Thorley and E. Plate. 2015a. Lower Duncan River Kokanee Spawning Monitoring (DDMMON-4) - Year 6 Data Report. Report Prepared for: BC Hydro, Burnaby. Prepared by: Okanagan Nation Alliance and LGL Limited. 23 pp + 1 App.

Zimmer, M., K. Beach, J. Thorley and E. Plate. 2016. Lower Duncan River Kokanee Spawning Monitoring (DDMMON-4) - Year 7 Data Report. Report Prepared for: BC Hydro, Burnaby. Prepared by: Okanagan Nation Alliance and LGL Limited. 35 pp + 1 App.

Zimmer, M., E. Plate, J. Thorley and A. Duncan. 2017. Lower Duncan River Kokanee Spawning Monitoring (DDMMON-4) - Year 9 Data Report. Report Prepared for: BC Hydro, Burnaby. Prepared by: Okanagan Nation Alliance and LGL Limited. 28 pp + 1 App.

Water Survey of Canada. 2016. Search for water temperature and discharge levels in the Lower Duncan River below Duncan Dam. Available: https://wateroffice.ec.gc.ca/report/report_e.html?type=realTime&stn=08NH118. Accessed on: Date

# 6. APPENDIX A – LDR KOKANEE SPAWNER MAPPING 2017


5566000
504000 5565000
504000
116°57'0"W
50°14'0"N
50°15'0"N
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
0
0.1
0.2
0.3
0.4
R1.1
0.5
0.6
0.69
MAP 1
Legend
River Kilometre
Side Channel Kilometre
Kokanee Spawning Use
Kokanee Holding (2017 - None observed)
Kokanee Spawning Use - Area Lost (2017 - None observed)
Kokanee Migrating (2017 - None observed)
1:5,000
0 100 200 300
Metres
BC Hydro
DDMMON - 4 Lower Duncan River Kokanee Spawning Monitoring
2017 Kokanee Spawning Areas
Ortho Date : October 2012
GIS File: LDR_5000_report2017data_20180131.mxd
Project Number: EA3745
DATE: 2018.02.21
PROJECTION: UTM Zone 11
REVISION DATE: January 2018
DATUM: NAD83
PRINTING DATE: 2018.02.21

5564000
5563000
1.9
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3
3.1
3.2
3.3
3.4
3.5
3.6
0
0.1
0.2
L2.7
0.3
0.4
0.5
0.6
R3.5
MAP 2
Legend
River Kilometre
Side Channel Kilometre
Kokanee Spawning Use
Kokanee Holding (2017 - None observed)
Kokanee Spawning Use - Area Lost (2017 - None observed)
Kokanee Migrating (2017 - None observed)
1:5,000
0 100 200 300
Metres
BC Hydro
DDMMON - 4 Lower Duncan River Kokanee Spawning Monitoring
2017 Kokanee Spawning Areas
Ortho Date : October 2012
GIS File: LDR_5000_report2017data_20180131.mxd
Project Number: EA3745
DATE: 2018.02.21
PROJECTION: UTM Zone 11
REVISION DATE: January 2018
DATUM: NAD83
PRINTING DATE: 2018.02.21
50°14'0"N
116°58'0"W

MAP 3
Legend
River Kilometre
Side Channel Kilometre
Kokanee Spawning Use
Kokanee Holding (2017 - None observed)
Kokanee Spawning Use - Area Lost (2017 - None observed)
Kokanee Migrating (2017 - None observed)
1:5,000
0 100 200 300
Metres
BC Hydro
DDMMON - 4 Lower Duncan River Kokanee Spawning Monitoring
2017 Kokanee Spawning Areas
Ortho Date : October 2012
GIS File: LDR_5000_report2017data_20180131.mxd
Project Number: EA3745
DATE: 2018.02.21
PROJECTION: UTM Zone 11
REVISION DATE: January 2018
DATUM: NAD83
PRINTING DATE: 2018.02.21

5.7
5.8
5.9
6
6.1
6.2
6.3
6.4
6.5
6.6
6.7
6.8
6.9
7
7.1
7.2
7.3
7.4
7.5
R6.9
0
0.1
0.2
0.3
0.4
0.5
0.57
MAP 4
Legend
River Kilometre
Side Channel Kilometre
Kokanee Spawning Use
Kokanee Holding (2017 - None observed)
Kokanee Spawning Use - Area Lost (2017 - None observed)
Kokanee Migrating (2017 - None observed)
1:5,000
0 100 200 300
Metres
BC Hydro
DDMMON - 4 Lower Duncan River Kokanee Spawning Monitoring
2017 Kokanee Spawning Areas
Ortho Date : October 2012
GIS File: LDR_5000_report2017data_20180131.mxd
Project Number: EA3745
DATE: 2018.02.21
PROJECTION: UTM Zone 11
REVISION DATE: January 2018
DATUM: NAD83
PRINTING DATE: 2018.02.21


R6.9
R7.6
L8.2
7.4
7.5
7.6
7.7
7.8
7.9
8
8.1
8.2
8.3
8.4
8.5
8.6
8.7
8.8
8.9
9
9.1
9.2
9.3
9.4
9.5
9.6
9.7
9.8
9.9
10
10.1
10.2
10.3
10.4
MAP 5
Legend
River Kilometre
Side Channel Kilometre
Kokanee Spawning Use
Kokanee Holding (2017 - None observed)
Kokanee Spawning Use - Area Lost (2017 - None observed)
Kokanee Migrating (2017 - None observed)
1:5,000
0 100 200 300
Metres
BC Hydro
DDMMON - 4 Lower Duncan River Kokanee Spawning Monitoring
2017 Kokanee Spawning Areas
Ortho Date : October 2012
GIS File: LDR_5000_report2017data_20180131.mxd
Project Number: EA3745
DATE: 2018.02.21
PROJECTION: UTM Zone 11
REVISION DATE: January 2018
DATUM: NAD83
PRINTING DATE: 2018.02.21
LGL
50°11'0"N
116°57'0"W

L8.2
0.5
0.6
0.7
1.1
1.2
1.3
1.4
1.5
1.6
1.68
10.3
10.4
10.5
10.6
10.7
10.8
10.9
11
11.1
11.2
11.3
11.4
11.5
11.6
11.7
11.8
11.9
12
12.1
12.2
12.3
116°56'0"W
MAP 6
Legend
River Kilometre
Side Channel Kilometre
Kokanee Spawning Use
Kokanee Holding (2017 - None observed)
Kokanee Spawning Use - Area Lost (2017 - None observed)
Kokanee Migrating (2017 - None observed)
1:5,000
0 100 200 300
Metres
BC Hydro
DDMMON - 4 Lower Duncan River Kokanee Spawning Monitoring
2017 Kokanee Spawning Areas
Ortho Date : October 2012
GIS File: LDR_5000_report2017data_20180131.mxd
Project Number: EA3745
DATE: 2018.02.21
PROJECTION: UTM Zone 11
REVISION DATE: January 2018
DATUM: NAD83
PRINTING DATE: 2018.02.21